The WRP Notebook

CONTENTS

Procedures For Evaluating Wetlands Non-Market Values and Functions

PURPOSE: This technical note provides a procedural framework for evaluating the economic values of wetlands. Important economic concepts on supply/demand and valuation are presented as they relate to the economic values supported or provided by wetlands. The framework presented here can be used to evaluate economic values within the Section 404 process, while recognizing the difficulties of wetland valuation. Economic values of wetlands have been difficult to evaluate due to uncertainties in the relationship between wetland functions and the production of goods and services. Production of some wetland goods and services is better understood than others. Just as there are changes over time in wetland habitat and other functions, economic values of wetlands change over time and should be accounted in the Section 404 evaluation process.

BACKGROUND: Wetlands perform many functions that provide goods and services to society and have economic value (Shabman and Batie 1988). To be of economic value, there must be a demand for the good or services. However, providing the good or service alone does not result in economic value if there is no demand. Goods or services may be in over-supply or available at no cost. Consequently, only those goods or services for which there is demand have economic value.

The focus of wetland assessment within the context of the Section 404 Program is the determination of the effects of a proposed action on a wetland site. For economic considerations, this focus must be expanded because the economic values associated with a single site are determined, in part, by the affected area's relationship to local, regional or larger economic conditions. To assess the potential for economic value, the relationship and significance of the wetland site's economic services within the larger economic context must be established. Information in this technical note provides the basis for establishing the potential relationship between an affected wetland and the market and other economic conditions that determine its economic value, as previously outlined in an internal working document. Henderson, J.E. 1991. "A Conceptual Plan for Addressing Wetland Economic Values," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

EVALUATION FRAMEWORK: A quantitative dollar and cents evaluation is not possible with, nor the intent of, this framework. Depending on the particular wetland and functions being assessed and other available information, a determination of economic value can be made in some situations. In most cases, this information then will form the basis for more in-depth data collection and analysis. Goods and services provided by wetlands are shown in Figure 1. The relationship between functions and economic goods and services is summarized in Table 1.

Those wetland functions possessing high functional capacities can be related to economic goods and services by examining the relationships in Table 1. Wetland functions are listed in column 1. The value of the function to society, that is, the importance and significance of the function, is briefly described in column 2. After the assessment, those functions with high functional capacities (col. 1) should be examined to determine potential economic value by relating them to the goods and services (col. 3, Table 1). Information on the goods and services as described below can assist in determining

Wastewater Treatment/Water Quality Flood Control Fish and Wildlife Habitat Land Development Recreation Water Supply Educational/Cultural Food and Fiber Wetland Production Services Commercial Fisheries, Agriculture, Timber

Figure 1. Economic Goods and Services

whether economic values exist. "Supply/demand" information describes how goods and services are provided to society and their relation to local, regional, or larger contexts. Information on "valuation considerations" explain the technical basis for determining economic value. Information about markets and other data that is not a part of the functional assessment will be needed to complete the economic evaluation. Table 2 summarizes the information needs and additional sources.

- Wastewater Treatment/Water Quality. Evaluating the economic benefits for water quality requires determining the value of improved water conditions. These benefits can be determined by establishing relationships between inflow sediment and pollutant characteristics, storage capacity, sediment retention and nutrient transformation capacity. The construction and other costs associated with providing alternative water quality treatment can be used to value the water quality improvement attributable to the wetland.

  Key Considerations are areal scale of changes in water quality services; i.e., assessment of whether the changes in water quality at the wetland is significant to the overall water quality of the watershed or basin, or whether the loss of water quality is a localized effect; structural and non-structural water quality measures; and appropriate water quality standards.

  Demand/Supply Considerations are magnitude and areal extent of effects on downstream water quality; changes in sediment, nutrient, and other water quality parameters for downstream reaches; contribution and significance of affected wetland to localized water quality.

  Valuation Considerations where Value = (Cost of using alternative) minus (Costs of using wetland). Value of wetland water quality services requires identifying the alternative means (e.g. structures, treatment) and costs to provide the same level of water quality improvement provided by the wetland. Costs of continued use of an unaltered wetland may be negligible, but there may be opportunity costs for not using the wetland for other benefits, e.g. habitat, which may be incompatible with wastewater treatment/water quality services.

- Flood Control. Evaluation of flood control benefits requires estimating flood damages with and without the wetland's flood control capacity. These benefits can be determined by establishing the relationships between wetland flood storage capacity and flood damages downstream, and the costs of providing alternative flood control structures or provisions for flood control.

  Key Considerations: Existing structures, floodplain measures, and plans for flood control may provide adequate level of flood control; i.e. wetland storage may not be needed (demanded) for flood protection, and may therefore not be of economic value. Wetland storage may be a localized effect, not significant on a watershed or regional scale.

Table 1. Relationship of Wetlands Functions to Economic Goods and Services		
Functions	Value of Functions	Economic Goods and Services
Detain, remove, and transform contaminants	Maintain surface and groundwater quality	Wastewater treatment/water quality
Detain and remove sediments	Maintain surface water quality	Wastewater treatment/water quality
Provide ecosystem, landscape and global integrity	Maintain ecosystem, landscape, and global processes	Educational/Cultural Habitat
Provide wetland ecosystem structure	Maintain populations of wetland dependent plants and animals species, preserve endangered species, maintain biodiversity, provide dispersal corridors	Fish and wildlife habitat
Provide a setting for cultural activities	Produce food and fiber, provide recreational opportunities, provide education and research opportunities, provide aesthetic enjoyment, preserve archaeological/historic sites	Commercial fisheries; agriculture, timber, peat production Education/Cultural
Store surface water	Reduce flood-related damage	Flood control
Reduce the energy level of surface water	Reduce erosion from storms and floodwater	Land development
Recharge groundwater	Maintain pumpable supplies of groundwater	Water supply
Discharge groundwater	Maintain stream and lake water levels	Water supply
Stabilize soils	Reduce erosion of shorelines and streambanks from storms and floods	Land development
Detain, remove, and transform nutrients	Maintain surface and groundwater quality	Wastewater treatment/water quality

Table 2. Information Needs

Available from Wetland Functional Assessment	Not Available from Wetland Functional Assessment
Wastewater Treatment/Water Quality Sediment and contaminant retention and transformation capacity Water storage capacity	Wastewater Treatment/Water Quality Regional water quality, wastewater treatment plans Costs of structural alternatives
Flood Control Storage Capacity Downstream land uses and floodplain	Flood Control Areal extent of flood protection provided by wetland Flood damage estimates
Habitat Habitat types affected Threatened and endangered species habitat affected	Habitat Plans and costs for replacement of wetland
Land Development Size, configuration of affected wetland Proximity to roads, infrastructure	Land Development Land market (real estate) transaction data Plans and costs for replacement of wetland
Recreation Areal extent of recreation resource Habitat quality to support consumption, i.e. hunting and fishing Indication of types of possible recreation activities possible	Recreation Supply of regional recreation resources and significance of affected wetland (quantity and quality) for regional resources Recreation user characteristics: Distance traveled and travel costs Age, income, and other demographic distributions Mix of types of recreation use Institutional considerations on demand, e.g. bag and catch limits, hunting and fishing seasons Willingness to pay values
Water Supply Potential of wetland to discharge and recharge groundwater Hydrology and groundwater relationships	Water Supply Existing infrastructure for providing water supply Engineering or other alternatives and costs for water supply
Educational/Cultural Screening for Red Flags Access to the affected wetland Scarcity/Abundance of affected wetland type Vegetation, landform, water components and other factors important for visual quality assessment Public review comments on issues of proposed action	Educational/Cultural Public concerns regarding local and regional wetlands, historic values and aesthetics State and local laws and policies regarding Red Flag issues
Food and Fiber Wetland Production Land uses and patterns Habitat, vegetation, soils and information important for evaluation of production potential	Food and Fiber Wetland Production Regional production patterns Market specific information, e.g. market prices, production costs

Supply/Demand Considerations are areal extent of flood protection provided; importance and value of downstream land uses, e.g. agriculture, residential or urban development; existing flood control or storm surge projects providing flood protection to the same area; existing comprehensive flood control/floodplain protection plans or programs; and possible induced private or public development actions (construction, regulation) if flood storage were reduced.

Valuation Considerations where Value = (Value of flood damages without wetland storage) minus (Value of flood damages with wetland storage), require determination of aerial extent of flooding with and without the wetland storage and valuation of flood losses under the above with and without conditions.

- Fish and Wildlife Habitat. A number of wetland functions support wetland fish and wildlife habitat services that may have economic value as existence, preservation and bequest--the nonuse values; and habitat as input to other economic values of recreation, educational/cultural, and production services--use values considered elsewhere in the text. Little work has been done to estimate the economic benefits of the nonuse values, with most of the effort on quantifying habitat quality.

  Key Considerations are scarcity of habitat types and importance/significance of habitat on a landscape, ecosystem, or regional basis; the ability to effectively create substitute wetlands through construction or restoration; and altered wetlands may also provide (or be managed to provide) habitat.

  Supply/Demand Considerations are areal extent and significance of affected wetland habitat in local, regional or ecosystem context; habitat quality of affected wetland; importance of affected habitat for species life stages or migration; habitat for threatened or endangered species; availability of replacement habitat; and feasibility, in terms of available technology, and success associated with replacement of the particular habitat type.

  Valuation Considerations where Value = Costs of a substitute for the habitat services. Costs associated with monitoring and maintenance should be included with the engineering and other construction costs. Although there is increasing information on costs of substitutes (necessary for valuation) through creating, constructing, or replacing wetlands, there is uncertainty in the ability of substitute wetlands to successfully or effectively replace the affected functions or habitat. Evaluation should include ability to ensure substitute will actually provide the same habitat.

- Land Development. Pressures for changes in land use often result in the conversion of wetlands to agricultural, forestry, urban, and water based residential uses. Agricultural and forestry uses (considered elsewhere in this text) are often a transitional stage in the conversion to urban uses. The aesthetic and waterfront location amenities of wetlands result in extensive pressure to convert wetlands to residential development. Valuation of residential land development is possible because markets exist for residences.

  Key Considerations are residential land sale transactions or real estate appraisals can be used to value land development; the services provided by unaltered wetlands, e.g. habitat, educational / cultural, should be considered as well as the services that could be provided by modified development to minimize impacts or losses; and value of wetland characteristics must be isolated from the value of any existing improvements.

Supply/Demand Considerations are availability of non-wetland sites, with similar amenities, for development (in some areas, wetlands may indeed offer the only site for waterfront and other amenities); existence and stability of a functioning local land market; and historic change in prices, i.e. whether or not any dramatic changes in land market has occurred in recent time period indicating increased demand.

Valuation Considerations. Both approaches depend on identifying feasible alternative development plans that reduce the need for wetland conversion. If a non-wetland alternative for development exists, Value = (Value of wetland development site) - (Value of next best alternative) and if no development alternative exists, Value = (Sale price of developed lot) - (Cost of developing the lot).

Two approaches, hedonic valuation or appraisal methods, may be used. Both are based on the market value of wetland residential development sites; hedonic approach requires enough market transactions to develop a statistical model.

Hedonic valuation studies identify and value different characteristics of wetland development sites and quantify the importance of development site characteristics to the market value of wetland residential sites. Site characteristics important to development are categorized as site amenities, location factors, and historical factors; examples are site amenities, lot size; level of waterfront amenities, such as linear fee of water frontage, whether the lot isolated on a natural bay or a man-made channel; proximity to unaltered wetlands; market value of improvements; location factors, location advantage provided to residence by proximity to shopping centers and other public services; and historical factors, change in general price levels in local or regional real estate markets.

In comparing the value of substitutes, comparability of identified alternatives should ensure the lots are really comparable in terms of the wetland based amenities and are not actually alternative development sites with different types or levels of amenities; consideration of value of improvements to development sites should include only site development and improvement for a building site. Modifications of a land parcel beyond that required to prepare the site to a minimum standard necessary to provide residential housing services should not be included. Extensive wetland site modifications do not contribute to the net development value of a wetland area as they provide services that are not unique to the wetland development.

Appraisal methods use the expected sale price for residential parcels to estimate the value of wetland development. The market comparison appraisal approach uses data from comparable parcels to infer the market value of a lot. Land market sales records, tax records, and local real estate experts can be used to support this method. Establishing comparable sales requires that adequate market data be available. An alternative appraisal method is the replacement cost method which establishes market value for replacement of the physical aspects of the site; that is the cost of building on another equivalent wetland site.

- Recreation. Wetland areas support recreation for consumptive, i.e. hunting and fishing, and non-consumptive purposes, e.g. wildlife viewing (considered under Educational/Cultural). Recreation use is determined in part by the biological productivity of the wetland in producing game species, and by available access and size of the recreation area, both of which are available from a regulatory application. Additional determinants of demand are demographic characteristics, e.g. age, income, travel time; experiential aspects, e.g. years of recreation experience, importance of bag or catch to the user, congestion at the recreation site; and institutional constraints on bag or catch limits and season length.

Valuation of recreation for regulatory actions should include identification of types and extent of recreation occurring in the larger region; assessment of the quantity and quality of the recreation resources at the site; identification of possible alternative sites for activities; and estimation of future recreation both with and without the proposed development, with consideration being given to recommending modified development, that is, incorporation of recreation opportunities, e.g. access, in development plans.

Key Considerations. Evaluation requires certain assumptions about the relationship between recreation use and wetland habitat and other resources. These relationships are required to predict changes in recreation use in response to development.

Demand/Supply Considerations. The assessment procedure should determine the magnitude and significance of changes in available recreation resources due to development of the wetland area. There may be substitutes for the range of wetland recreation activities at different sites. Displaced recreation may move to other under-used areas or cause overuse at already congested areas; these conditions should be considered in the evaluation. Supply can be assessed in terms of quantity of recreation resources, e.g. number of acres; quality of the resources, including quality of access. Demand is usually approximated by the complex interactions of wetland resource attributes; user characteristics which act as demand shifters are such things as taste, preferences, income, hunting or fishing success; institutional constraints; and the availability of appropriate substitutes or alternatives. General information on existing recreation use may be available from state or local fisheries and wildlife management agencies.

Valuation Considerations where Value for wetland recreation at a site = (willingness to pay (WTP) to recreate at the wetland site) - (WTP for same activities at next best alternative). This formula requires identifying alternative recreation sites and evaluating WTP values for both the affected wetland and for the substitute.

Accepted valuation methods for WTP are the travel costs method that uses costs of travel and time as proxies for WTP; the contingent valuation method in which users respond to proposed wetland recreation conditions; and the Unit Day Value Method which assigns a standardized value to the quality and other characteristics of recreation resources.

- Water Supply. The ability of wetlands to recharge and discharge groundwater can provide water supply services. There are few documented uses of wetlands for water supply due to uncertainty in interactions between wetlands and groundwater and in the capacity to use wetland water supplies without damaging the wetland itself. Better understanding of wetland hydrology and wetland-aquifer interactions may change demand for wetland water supply services. Engineering costs for providing water supply are generally available and can be used to value the costs of alternatives for wetland water supplies.

  Key Considerations. Valuation of wetland water supply is dependent on establishing demand or need for the water; relationship between affected wetland area and the local groundwater supply; and valuation of the alternatives or substitutes for the wetland water supply.

  Supply/Demand Considerations. In many areas, wetlands serve as secondary, rather than primary, water supply sources. Evaluation requires establishing the extent of potential local or regional demand for the wetland water. Groundwater recharge and discharge capacity and areal and hydrologic measurements can be used to determine potential water supplies, but these must be compared to the demand for additional water. Local or municipal water supply agencies provide information on existing supply and costs.

Valuation Considerations. Valuation is determined by the availability of alternative water supply. If no alternative exists for the wetland water supply services, Value = value of the water supply to the consumer. If alternatives exist, Value = (costs of development of wetland water supply) - (costs of development of alternative water supply sources).

Evaluating differences in costs between the wetland and an alternative water source entails determining the costs of alternative sources and then comparing those costs to those of the wetland source. Identification of the least cost alternative is not straightforward since little use and costs data for wetland water supplies exist. Engineering and hydraulics personnel can provide development costs for alternative water supply, and public utility records can be used for unit costs of water.

- Educational/Cultural. Educational/cultural goods and services provided by wetlands are based on the significance of wetlands for human uses and preservation. Educational/cultural services are composed of natural, scenic, or aesthetic values; historic, archaeologic, or public use values; and non-consumptive recreation values, e.g. bird watching (consumptive recreation is covered in recreation). Monetary valuation is not normally attempted or appropriate. Rather, significance or technical ratings of quality are determined for the components.

Key Considerations. It is often difficult to separate educational/cultural services from the provision of other goods and services, e.g. flood control. These values derive from the existence of the wetland in a natural or undisturbed state, rather than the value derived from some use of the wetland.

Supply/Demand Considerations. Visual quality characteristics and potential for recreation in the affected wetland are evaluated in terms of regional scarcity and quality. The question is "Are the visual and recreational resources unique or scarce, and will there be a significant loss with development?" The visual quality is determined by the relative uniqueness of vegetation, water, landform, etc, and whether these visual characteristics are unique or abundant in the region. For recreation, wetland size, public access and use, and availability of substitutes in the region must be considered. Historic and cultural resources must be identified and their significance determined, if present. The wetland may be of cultural significance because it of its role in providing food, fiber and other necessities for groups engaged in subsistence economies.

Valuation considerations consist primarily of visual quality applications. Wetlands provide visual diversity in upland and especially urban environments. Wetland aesthetics have been evaluated and show variation between regions. Studies have related wetland characteristics to overall visual quality with varying levels of success. Other things being equal, people prefer open water/marshy wetland areas to thickly vegetated shrub/woody swamps where visual access is impaired. Visual quality is related primarily to the shape of the upland wetland edge, the vegetation/water interspersion pattern, and pattern or relation of types of vegetation or vegetation classes. Shape of wetland/upland edge: Irregular, non-straight line edges have higher visual quality. Vegetation/water interspersion pattern: Mosaic patterns of vegetation interspersed among channels, pools, and flat water areas are of higher visual quality than intermediate conditions or well defined vegetation areas with little or no interspersion. Vegetation class interspersion: Mosaics of vegetation types or classes of similar heights are of higher visual quality than well defined areas of single vegetation types with little or no interspersion.

Historic Values: Screening for Red Flags during the evaluation process determines whether or not the affected wetland is protected under Federal policy; applicable State and local screening criteria should be identified. Potential impacts to protected historic or archaeologic resources should be evaluated by District personnel.

Non-consumptive Recreation: Non-consumptive recreation potential is determined by physical access to the wetland areas and the abundance and diversity of wetland vegetation, wildlife and other resources necessary for recreation.

- Food and Fiber Wetland Production Services. Habitat functions support agriculture, forestry, and commercial fishery production. Economic valuation is determined by market conditions, and production functions that incorporate production factors and supply and demand considerations.

Key Considerations. For commercial fisheries, linkage must be established between habitat availability, habitat productivity; production costs, e.g. harvest; and changes in the wetland. Little data is available on valuation of wetland forest management of conversion to intensive silviculture. Decisions on agricultural production, on the other hand, are complicated by provisions of the Food Security Act (Swampbuster).

Supply/Demand Considerations. Alternatives or substitutes for production services should be identified to determine in value in the differences between wetland production and the next best alternative. Commercial fishery market prices and costs of production are obtainable. Timber production in a wetland or wetland conversion for timber is responsive to the local and regional timber market and future changes in those markets.

Valuation Considerations. Commercial fisheries, agriculture, and forestry are market based so valuation of a wetland is dependent on regional markets. Valuation must consider whether the service can be produced elsewhere, i.e., whether there is a production alternative. The value of the wetland production services is measured as the change to the economic surplus, i.e, return of the wetland to private owner. Value of wetland for production: (Net returns from production from wetland harvest) - (Net returns from production from next best alternative).

Fisheries. Valuation of wetland fisheries is determined by production models relating changes in catch to changes in production factors, e.g., habitat size, water quality, level of harvest effort. Changes in catch can then be multiplied by the market price of the fish. Difficulties in this approach, known as marginal value product method, are in formulating a production function.

Agriculture. Decisions to convert wetlands to agricultural production must account for the profitability of different crops given the market for respective crops; government price supports and targets; availability of suitable non-wetland rental lands; and the Swampbuster provisions of the Food Security Act (making farmers ineligible for government supports if crops are grown on converted wetlands). Value is measured by the projected change in return to the farmer.

Forestry. Value for timber production is the stumpage value, i.e. the value of the timber that can be cut off the site, if there is no alternative for timber production. If alternative sites exist, then value is the difference between the returns to development and returns to development of the next best alternative.

CONCLUSIONS: The economic evaluation framework presented in this technical note uses and builds on information obtained when assessing wetland functions and their relationships to economic goods and services. For those wetland functions assessed as having a high functional capacity, a method is to determine whether or not there is potential for economic value is outlined.

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Methods for Evaluating Wetland Functions

PURPOSE: The purpose of this technical note is to review the major wetland evaluation methods currently in use among wetland professionals and to provide a comprehensive list of these methods for use by field biologists and managers. Method selection can be based on study objectives; amount of time, budget and personnel available; regional or local controversy; and degree of precision and accuracy required.

REVIEW PROCESS: A total of 17 methods were reviewed. These methods are widely used and have applicability to the Section 404 review process. The analysis compared the similarities and differences between the variables used to assess wetland functions. Four of the methods reviewed are designed for generalized use: the Habitat Evaluation Procedures (HEP), Habitat Assessment Technique (HAT), Wetland Evaluation Technique (WET), and Ontario Method. These four, and other methods which are more region specific, are listed in Table 1 by author and by their commonly accepted names.

We grouped wetland functions into four broad categories: hydrology/water quality; landscape integrity; fish and wildlife/habitat; and recreation/aesthetic. Each method was reviewed to determine if it addressed the major functional categories and the types of variables used to measure the functions (Table 1.) Three previous reviews of methods addressing different issues may be of use to supplement this review.[1]

No consensus was evident on the numbers of variables used to evaluate wetland functions. The WET addresses the greatest number of variables (94), and HAT, the fewest (3). Collectively, the 17 methods address 300 variables (Table 1). However, the number of variables that three or more methods have in common was 78: hydrology/water quality (16), landscape integrity (31), fish and wildlife/habitat (13), and recreation/aesthetic (18). This smaller list has been compiled into Table 2 and may be useful to evaluators and reviewers of permits to reduce the number of variables included in the analysis. Generally, a greater number of variables will increase time and cost of the analysis. Conversely, too few variables may not provide enough information for sound decision making.

- Hydrology/water quality. Fifteen of the methods included variables related to hydrology/water quality (Table 1). Of these methods, three used three or less variables to evaluate this category. The most comprehensive series of variables was contained in WET with 28, although several methods used 12 or more variables.

- Landscape Integrity. All of the methods included one or more variables to evaluate landscape integrity. Four methods evaluated this category with four or fewer variables (Table 1). The greatest number of variables was included in HEP with 35.

[1] See Lonard et al. (1981), Kusler and Riexinger (1986), and Adamus (1989) in the suggested-reading section.

- Fish and Wildlife/habitat. Thirteen methods included one or more variables to evaluate fish and wildlife/habitat (Table 1). HEP used the greatest number of variables at 27. Six used four or less variables to evaluate this category.

- Recreation/aesthetic. Thirteen methods included one or more variables to evaluate the recreation/ aesthetics category (Table 1). Six used four or less variables. The Wetland Evaluation Guide used the most comprehensive list of variables at 47.

RECOMMENDED ADDITIONAL READING:

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Table 1
Variables Used for Wetland Evaluation

Variables	**Methodologies** 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Hydrology/Water Quality																	
Abundance of cover in stream/ river										X						X	
Alkalinity												X					
Bacterial concentration			X									X					
Bank stabilization																	X
Bottom water temperature										X		X					
Climate regulation	X											X					
Condition of shoreline													X				
Constriction of wetland												X					
Contribute to groundwater quality	X	X	X				X					X				X	
Contribute to groundwater quantity							X										
Contribute to surface water quality	X	X	X						X			X					
Contribute to usable surface water	X																
Dispersal of toxics	X																
Dominant flooding regime												X					
Downstream sensitivity													X				
Erosion control	X	X		X					X				X	X			
Flood damage potential downstream													X				
Flood flow alteration			X									X					
Flood peak flows													X				
Flood protection/control	X			X					X							X	
Flood tolerance index																	
Flood water desynchron. and stor.		X														X	
Flooding extension and duration											X	X	X				

1 Witty et al., Wetland Eval. Guide.
2 Gosselink, Le, Cum. Ass. of BLH.
3 Cooper et al., Intermount Riparian.
4 Anchorage Assess.
5 Golet, Freshwater NE.
6 Smardon, Fabos, Vis./cultural Model
7 Heeley, Motts, Groundwater Restor.
8 Cable et al., HAT.
9 Marble, Gross, Assess. Wet. Chairs.
10 USFWS, HEP.
11 O'Neil et al., BLH.
12 Adamus, WET II.
13 CORPS, WEM.
14 Euler et al., Ontario Method.
15 Hollands, McGee, H&M.
16 Ammann, Stone, NH/CONN Meth.
17 North Carolina Meth.

(Sheet 1 of 11)

Table 1 (Continued)

Variables	Methodologies 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Hydrology/Water Quality (Continued)																	
Flooding frequency													X				
Flow augmentation	X	X										X		X			
Flow retention				X													
Flow stabilization				X										X			
Flow variation			X														
Flow, gradient, deposition												X	X				
Groundwater discharge			X									X					
Groundwater recharge	X		X									X					
Growing degree-days														X			
Heavy metal concentration			X							X							
Hydrologic connection															X		
Hydrologic position															X		
Living filter																	
Measure of D.O.			X							X		X	X				
Nutrient levels	X	X	X	X						X			X	X			
Nutrient removal												X		X			X
Nutrient retention		X										X				X	
Physical char. of stream channel										X						X	
Poorly drained soils-% of wetland																X	
Precipitation rate												X					
Presence of inlets/outlets												X			X		
Presence of springs													X				
Pres./abs. of temp. pools of water										X							
Production exports (organics)			X									X			X		
Recharge to regional aquifer	X		X														
Reduction of tidal impacts	X																
Salinity and conductivity of water										X		X					
Sediment flow stabilization	X		X									X					
Sediment removal																	X

(Sheet 2 of 11)

Table 1 (Continued)

Variables	Methodologies																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Hydrology/Water Quality (Continued)																	
Sediment trapping		X	X						X			X	X			X	
Shoreline anchoring													X				X
Slope of watershed above wetland																X	
Storage of agriculture runoff	X																
Storage/recycling of human waste	X																
Streambank shade			X							X						X	
Surface drainage																	X
Surface substrate type												X					
Surface water persistence				X											X		
Suspended solids										X		X					
Toxicant removal																	X
Toxicant retention												X					
Transmissivity of aquifer															X		
Underlying glacial material							X										
Water catchment	X																
Water chemistry					X												
Water conveyance																	X
Water depth										X		X	X		X		
Water detention		X												X			
Water level fluctuation										X					X		
Water quality										X						X	
Water storage																	X
Water temperature										X		X					
Watershed protection	X								X								
Wetland hydroperiod																X	
Wetland outlet restriction																X	
Adjacent to tributary of Great Lakes													X	X			
Buffer zone for natural area										X							X
Contiguity among patches		X								X							X

(Sheet 3 of 11)

Table 1 (Continued)

Variables	Methodologies																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Landscape																	
Contiguity to stream/lake		X		X		X							X		X	X	
Contiguity to upland		X										X				X	X
Cover type					X					X		X	X				
Diameter of canopy layer trees										X	X	X					
Diameter/number/condition of snags										X		X					
Dominant wetland class					X								X		X	X	
Ecological age of wetland														X			
Edge bordered by a buffer-%										X						X	
Edge bordered by upland hbtt.-%										X						X	
Edge effect of commun. types				X		X					X	X		X			
Existing disturbance										X		X					
Fetch and exposure												X		X	X		
Fraction of type remaining		X															
Fringe wetland												X					
Gradient												X	X				
Ground cover-%										X	X						
Habitat diversity			X	X						X			X			X	
Internal wetland contrast						X						X		X			
Interspersion of shade												X				X	
Interspersion type					X				X	X	X	X			X	X	
Is area an island?												X					
Landform contrast																X	
Local topography											X	X			X		
Located at extreme limit of range													X				
Location and size of detention areas														X			
Long term stability																X	
Maintainance of biological diversity	X																
Open space or corridors										X			X				

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Table 1 (Continued)

Variables	Methodologies 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Landscape (Continued)																	
Open water types				X						X		X		X			
Open water-%															X	X	
Patch size distribution		X															
Position within watershed				X					X			X			X		X
Presence of fen or bog													X	X			
Presence of native prairie												X	X				
Presence of swamp or marsh														X			
Protection of natural shorelines	X																
Proximity to large water bodies										X		X					
Proximity to other wetlands				X	X	X				X		X	X	X	X	X	
Restoration potential/value																	X
Scarcity of type						X						X		X			X
Sensitivity to disturbance				X							X	X					X
Shrub cover-%											X					X	
Size of adjoining lakes and rivers														X			
Size of watershed	X									X		X				X	
Size of wetland		X	X	X	X	X		X	X	X		X		X	X	X	
Soils type				X						X		X		X			
Spatial diversity			X							X							
Stand maturity										X	X						
Stream corridor vegetation																X	
Subclass richness					X								X		X		
Surface substrate										X	X						
Surficial geology							X					X			X		
Surrounding habitat types					X					X				X	X		
Tree canopy closure										X	X						
Vegetation class interspersion										X		X	X				
Vegetation community structure				X						X	X						
Vegetation cover-%										X	X	X	X				X

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Table 1 (Continued)

Variables	Methodologies																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Landscape (Continued)																	
Vegetation density										X	X				X	X	
Vegetation diversity			X			X				X		X					
Vegetation type										X		X	X	X			
Vegetation-water interspersion										X		X				X	
Vegetative species richness										X					X		
Vegetative width										X		X					
Waterbody diversity						X										X	
Watershed position			X														
Water/cover ratio															X		
Wetland bordering open water-%										X					X		
Wetland class richness					X								X		X	X	
Wetland morphology																X	
Wetland type	X			X	X	X						X	X	X			
Wetland types within a wetland-#										X				X			
Width of wetland										X			X			X	
Wildlife access to other wetlands																X	
Wildlife/Habitat																	
Abund. of aquatic insects/inverts			X							X		X					
Biological control	X																
Bird species richness		X								X							
Breeding bird diversity				X						X							
Breed. hbtt. for endan. plants/ anim.														X			
Breed./feed. hbtt. for signif. species														X			
Dominance of robust emergents				X						X			X	X			
Identifiable guilds			X														
Mast production by trees										X	X						
Migration habitat	X			X								X					

(Sheet 6 of 11)

Table 1 (Continued)

Variables	Methodologies																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Wildlife/Habitat (Continued)																	
Migration or feed. hbtt. for T&E spp.														X			
Nursery habitat	X																
Plant productivity												X					
Presenceof coldwater fish species													X				
Presence/absence of indicator spp.		X								X							
Proportion of wildlife food plants										X					X		
Quailty of spawning substrate										X			X				
Quality habitat for plants and animals	X									X							
Rare/threat. endan. plants/animals	X	X		X								X	X	X	X	X	X
Scarcity of spawning habitat										X			X				
Significant habitat for aquatic life										X							X
Significant habitat for birds				X						X		X					
Significant habitat for crustaceans	X									X							
Significant habitat for fish		X	X	X						X		X					
Significant habitat for mammals	X									X							
Significant habitat for sport fish	X									X		X					
Significant habitat for wildlife	X	X	X							X		X					X
Significant waterfowl habitat	X									X		X	X	X			
Sig. habitat for reptiles/amphibians	X									X							
Sig. hbtt. for fish spawning/rearing										X			X	X		X	
Sig. nest. hbtt-colonial waterbirds										X				X			
Species diversity								X		X		X					
Submerged or emergent vegetat.-%										X						X	
Total area of pond or lake										X						X	
Unique fisheries															X		

(Sheet 7 of 11)

Table 1 (Continued)

Variables	Methodologies																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Wildlife/Habitat (Continued)																	
Uniqueness of species								X				X					
Unusual abundance of plants/animals	X											X					
Water dependent terr. organisms		X										X					
Waterbird migration populations	X			X								X		X			
Wetland depend. aquatic organisms		X										X					
Wetland plant communities-#				X						X							
Winter cover provided										X				X			
Winter fish kills													X				
Wintering habitat										X		X	X	X			
Recreation/Aesthetics																	
Absence of human disturbance										X				X			
Access to navigable waters													X		X	X	
Access to stream/pond/lake																X	
Add to visual diversity of area	X															X	
Adjacent development										X			X				
Adjacent to public lands													X				
Aesthetic quality																X	
Aids groundwater recharge regulation													X				
Ambient quality							X										
Amount of original wetland filled-%																X	
Archaeol./paleon. resources	X											X				X	
Area dominated by flowering trees-%																X	
Audio qualities	X									X							
Barriers to anadrom. fish (ie. dams)																X	
Boating opportunities	X													X			
Commercial harvest (hunt, trap, fish)	X											X		X			

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Table 1 (Continued)

Variables	Methodologies																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Recreation/Aesthetics (Continued)																	
Commercial uses (rice, peat)	X													X			
Contribute to local/regional economy	X													X			
Contribute to urban flood protection	X																
Direct alteration												X					
Distance from urban population	X											X		X			
Distance to education facility	X			X								X		X		X	
Distance to roads										X		X	X				
Dominant land use																X	
Dominant land use above wetland																X	
Ease of access	X			X			X						X	X	X	X	
Economic value																	X
Educational use	X			X		X						X	X	X			X
Enhance crop production	X													X			
Enhance development values	X																
Enhance urban water quality	X																
Existing alterations													X				
Fisheries management area																	
General appearance of wetland																X	
Handicap access																X	
Hazards limiting public use																X	
Historical area/buildings																X	
Important sightseeing locale	X												X				
Interpretive program	X			X										X			
Land use along river/stream														X			
Land use in watershed														X			
Land use patterns (general)													X				
Landscape distinctness														X			

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Table 1 (Continued)

Variables	Methodologies 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Recreation/Aesthetics (Continued)																	
Level of human activity in upland																X	
Level of human activity in wetland										X						X	
Local significance																X	
Location (public/private land)	X			X								X	X	X	X		
National natural landmark																X	
Noise level at viewing locales																X	
Number of visitors	X																
Occupied buildings along edge-#																X	
Occurence of mineral, gas, oil	X																
Odors present at viewing locales																X	
Offroad parking for buses/cars																X	
Open space function	X			X									X				
Opportunity for noncommercial use	X																
Part in pattern of settlement	X																
Part of heritage of region	X											X	X				
Photographic opportunity	X																
Plant alteration (ie. mowing)-%																X	
Policies/programs to conserve area	X											X					
Pollution													X				
Presence of harvestable resources	X											X					
Presence of mill pond																X	
Pres. of nature pres. or wildl. mgmt.																X	
Project benefits	X																
Proximity to tribal lands													X				
Proximity to wild and scenic river													X				
Public roads/railroad crossings-#																X	
Recreation diversity			X														

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Table 1 (Concluded)

Variables	Methodologies 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Recreation/Aesthetics (Continued)																	
Recreation experience (general)			X									X					X
Regulated by state or COE													X				
Scarcity of type						X							X		X		
Site of special public interest	X											X					
Source of forage	X																
Source of water for crop irrigation	X															X	
Source of water for livestock	X																
Source of waterfowl for consumption	X													X			
Sport hunting/fishing	X	X												X		X	
Student safety																X	
Tactile quality	X																
Tourism or recreation attraction	X																
Traditional use area	X																
Unique regional resource	X											X	X				
Unusual geol. or structural features														X		X	
Use for domestic water supply	X											X				X	
Use for scientific research	X			X		X						X	X	X		X	
Use for sewage treatment	X											X					
Use of water for industry	X																
Utilized for cultural events	X																
Visibility from highway	X																
Visibility of open water																X	
Visual diversity													X				
Visual dominance	X					X											
Watchable wildlife	X															X	
Wells that serve public												X				X	
Winter recreation	X													X			

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Table 2
Variables Used for Wetland Evaluation Appearing Three or More Times in the Literature

Variables	Methodologies																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Hydrology/Water Quality																	
Contribute to groundwater quality	X	X	X				X					X				X	
Contribute to surface water quality	X	X	X						X			X					
Erosion control	X	X		X					X				X	X			
Flood protection/control	X			X					X							X	
Flooding extension and duration											X	X	X				
Flow augmentation	X	X										X		X			
Groundwater recharge	X		X									X					
Measure of D.O.			X							X		X	X				
Nutrient levels	X	X	X	X						X			X	X			
Nutrient removal												X		X			X
Nutrient retention		X										X				X	
Production exports (organics)			X									X			X		
Sediment flow stabilization	X		X									X					
Sediment trapping		X	X						X			X	X			X	
Streambank shade			X							X						X	
Water depth										X		X	X		X		
Landscape																	
Contiguity among patches		X								X							X
Contiguity to stream/lake		X		X		X							X		X	X	
Contiguity to upland		X										X				X	X
Cover type					X					X		X	X				
Diameter of canopy layer trees										X	X	X					
Dominant wetland class					X								X		X	X	
Edge effect of commun. types				X		X					X	X		X			

1 Witty et al., Wetland Eval. Guide.
2 Gosselink, Le, Cum. Ass. of BLH.
3 Cooper et al., Intermount Riparian.
4 Anchorage Assess.
5 Golet, Freshwater NE.
6 Smardon, Fabos, Vis./cultural Model
7 Heeley, Motts, Groundwater Restor.
8 Cable et al., HAT.
9 Marble, Gross, Assess. Wet. Chairs.
10 USFWS, HEP.
11 O'Neil et al., BLH.
12 Adamus, WET II.
13 CORPS, WEM.
14 Euler et al., Ontario Method.
15 Hollands, McGee, H&M.
16 Ammann, Stone, NH/CONN Meth.
17 North Carolina Meth.

(Sheet 1 of 3)

Table 2 (Continued)

Variables	Methodologies 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Landscape (Continued)																	
Fetch and exposure												X		X	X		
Habitat diversity			X	X						X			X			X	
Internal wetland contrast						X						X		X			
Interspersion type					X				X	X	X	X			X	X	
Local topography											X	X			X		
Open water types				X						X		X		X			
Position within watershed				X					X			X			X		X
Proximity to other wetlands				X	X	X				X		X	X	X	X	X	
Scarcity of type						X						X		X			X
Sensitivity to disturbance				X							X	X					X
Size of watershed	X									X		X				X	
Size of wetland		X	X	X	X	X		X	X	X		X		X	X	X	
Soils type				X						X		X		X			
Subclass richness					X								X		X		
Surficial geology							X					X			X		
Surrounding habitat types					X					X				X	X		
Vegetation class interspersion										X		X	X				
Vegetation community structure				X						X	X						
Vegetation cover-%										X	X	X	X				X
Vegetation diversity			X			X				X		X					
Vegetation type										X		X	X	X			
Wetland class richness					X								X		X	X	
Wetland type	X			X	X	X						X	X	X			
Width of wetland										X			X			X	
Wildlife/Habitat																	
Abund. of aquatic insects/inverts			X							X		X					
Dominance of robust emergents				X						X			X	X			
Migration habitat	X			X								X					

(Sheet 2 of 3)

Table 2 (Concluded)

Variables	Methodologies 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Wildlife/Habitat (Continued)																	
Rare/threat. endan. plants/animals	X	X		X								X	X	X	X	X	X
Significant habitat for birds				X						X		X					
Significant habitat for fish		X	X	X						X		X					
Significant habitat for sport fish	X									X		X					
Significant habitat for wildlife	X	X	X							X		X					X
Significant waterfowl habitat	X									X		X	X	X			
Sig. hbtt. for fish spawning/rearing										X			X	X		X	
Species diversity								X		X		X					
Waterbird migration populations	X			X								X		X			
Wintering habitat										X		X	X	X			
Recreation/Aesthetics																	
Access to navigable waters													X		X	X	
Archaeol./paleon. resources	X											X				X	
Commercial harvest (hunt, trap, fish)	X											X		X			
Distance from urban population	X											X		X			
Distance to education facility	X			X								X		X		X	
Distance to roads										X		X	X				
Ease of access	X			X			X						X	X	X	X	
Educational use	X			X		X						X	X	X			X
Interpretive program	X			X										X			
Location (public/private land)	X			X								X	X	X	X		
Open space function	X			X									X				
Part of heritage of region	X											X	X				
Recreation experience (general)			X									X					X
Scarcity of type						X							X		X		
Sport hunting/fishing	X	X												X		X	
Unique regional resource	X											X	X				
Use for domestic water supply	X											X				X	
Use for scientific research	X			X		X						X	X	X		X	

(Sheet 3 of 3)

Wetlands Mitigation Evaluation: A Bibliography

PURPOSE: This technical note provides a bibliography of wetland mitigation evaluation techniques literature.

BACKGROUND: In 1990, the U.S. Army Corps of Engineers (USACE) and the U.S. Environmental Protection Agency (EPA) signed a Memorandum of Agreement (MOA) that provided guidance on wetland mitigation activities for Section 404 of the Clean Water Act of 1977 (formerly Federal Water Pollution Control Act), 33 USC 1344, as amended. The MOA references many complex scientific and technical provisions that involve wetland mitigation sequencing (avoidance, minimization, and compensation of adverse project impacts) to obtain full functional replacement for the impacted wetlands. One of the first essential steps in determining the present status of the scientific and technical body of knowledge was to conduct a review of the literature pertinent to wetland mitigation evaluation techniques.

APPROACH: In 1990, an initial literature review was conducted using state-of-the-art computer retrieval systems. Approximately 272 citations were identified. Most of the publications (or the publication abstracts) were obtained and reviewed for scientific or technical content. Policy or philosophical publications were not included. The final list of 24 references on wetland mitigation evaluation techniques was compiled into this bibliography.

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CONCLUSION: This bibliography provides planning, operations, natural resource management, and regulatory personnel with a bibliography of wetland mitigation techniques literature, thereby minimizing intensive, duplicative, and costly literature searches.

POINT OF CONTACT FOR ADDITIONAL INFORMATION: Mr. Robert L. Lazor, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-EP-W, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, Phone: (601) 634-2935.

WRP Technical Note WG-RS-3.1
May 1992

Wetlands Engineering: Design Sequence for Wetlands Restoration and Establishment

PURPOSE: This technical note describes a sequence of activities for design and selection of construction techniques for wetlands restoration and establishment. The design sequence includes consideration of wetlands needs, site characteristics, and design criteria; fill or excavation equipment and techniques for wetlands soils; water and erosion control structures for wetlands hydrology; and techniques and materials for establishing wetlands vegetation. Duplicative and unnecessary design evaluations can be avoided by following the guidance in this technical note (TN).

BACKGROUND: Guidelines pertaining to various aspects of wetlands design are available [Environmental Laboratory (1978), Federal Highway Administration (1990), Soil Conservation Service (in preparation)], and additional guidance is being developed as a part of the WRP Restoration and Establishment Task Area. This TN supplements the currently available guidance by describing a design sequence for wetlands establishment and restoration projects.

DESIGN SEQUENCE: The flowchart shown in Figure 1 illustrates the design activities for a wetlands restoration and establishment project and the sequence in which the activities should be considered. The overall sequence is based on the concept that design activities associated with establishing wetland substrate soils and hydrology should precede those associated with establishing wetland vegetation.

The numbered blocks in the flowchart in Figure 1 are referenced to the following brief descriptions of the activities:

(1) Conduct an initial evaluation of wetlands needs for the area under consideration for the restoration/establishment project.

(2) Select a desired set of wetlands functions and values for the project.

(3) Perform a baseline site survey in the project area to determine initial topographic, hydrologic, soils, and vegetative conditions.

(4) Prioritize and select specific sites for restoration and establishment within the project area.

(5) Determine design criteria for soils, hydrology, and vegetation based on desired functions and values and site characteristics as determined in Step 2.

(6) Determine if existing substrate soils and hydrology meet the design criteria. If substrate soils and criteria are adequate, proceed to Step 22 to evaluate wetlands vegetation requirements.

(7) Determine if substrate fill or excavation will be required. If existing substrate elevation and grading are adequate, proceed to Step 17 to evaluate water and erosion control measures.

(8) If fill or excavation will be required, determine substrate elevation and grading requirements to meet the design criteria (i.e. design the new substrate topography).

(9) Select borrow material sources for fill requirements and placement sites for any excavated material (preferably within the restoration/establishment site).

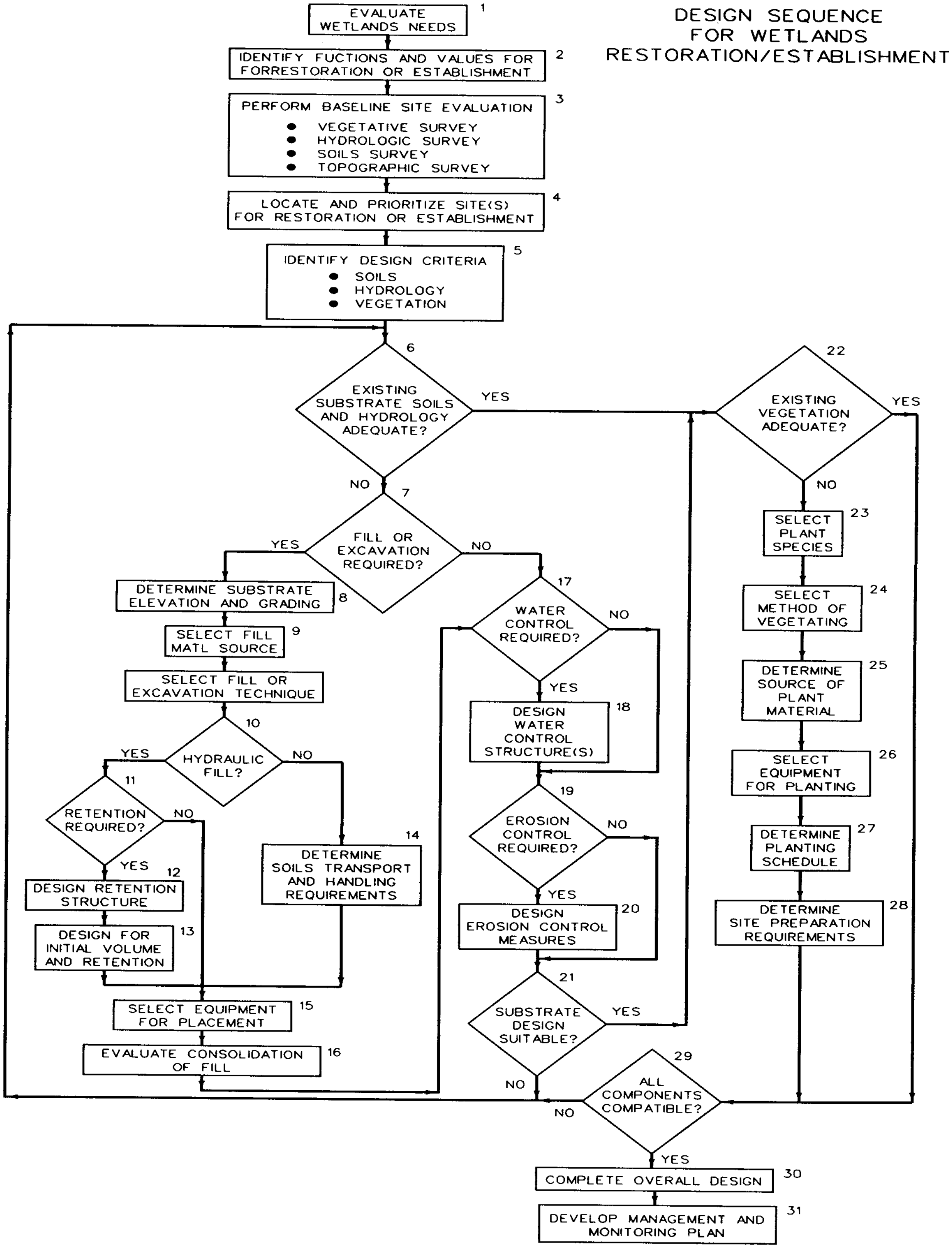

Figure 1. Flowchart illustrating design sequence for wetlands restoration and establishment projects

(10) Determine the most desirable fill or excavation process (i.e. hydraulic fill or conventional soils handling). If a conventional soils handling process is chosen, proceed to Step 14 to select soils handling requirements.

(11) If hydraulic fill is the desirable approach, determine if retention of the material will be required. If not, proceed to Step 15 to select the appropriate hydraulic dredging equipment.

(12) If retention of hydraulic fill is required, design the retention dike or structure.

(13) Design the retention area for initial volume of material to be placed hydraulically and for retention of suspended solids during placement.

(14) If conventional soils handling is the desirable approach, determine soils handling requirements.

(15) Select equipment for hydraulic placement or placement using conventional soils handling techniques.

(16) Predict consolidation of fill and account for consolidation in fill elevation and grading.

(17) Evaluate requirements for water control. If water control structures are not required, proceed to Step 19 to evaluate erosion control requirements.

(18) Design any required water control structure(s).

(19) Evaluate requirements for erosion control. If erosion control measures are not required, proceed to Step 21 to evaluate overall suitability of the substrate design.

(20) Design necessary measures for erosion control.

(21) Evaluate compatibility of all design components pertaining to substrate soils and hydrology. If compatible, proceed to Step 22 to evaluate vegetation requirements. If not, return to Step 6 to reevaluate requirements or designs associated with substrate soils and hydrology.

(22) Determine if adjacent vegetation is adequate and will colonize the restoration/establishment site in an appropriate time frame without active planting. If adequate, proceed to Step 29 to evaluate overall compatibility of design components.

(23) If active planting is required, select species for planting.

(24) Select method of vegetating (e.g. seeds, propagules, etc.)

(25) Determine source(s) of plant materials.

(26) Select equipment for planting.

(27) Determine planting schedule.

(28) Determine site preparation requirements.

(29) Evaluate overall compatibility of all components of design (soils, hydrology, vegetation). If not compatible, return to Step 6 to reevaluate requirements or designs.

(30) Complete overall design.

(31) Develop management and monitoring plan to include appropriate remedial actions.

Future TN's in the WRP series will provide more detailed information on the various activities included in this design sequence.

CONCLUSION: By following an efficient sequence of activities for design, unnecessary evaluations can be avoided and a fully integrated design will result.

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POINT OF CONTACT FOR ADDITIONAL INFORMATION: Dr. Michael R. Palermo, USAE Waterways Experiment Station, ATTN: CEWES-EE-P, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, Phone: (601) 634-3753.

Wetland Engineering in Coastal Louisiana: Mississippi River Delta Splays

PURPOSE: This technical note describes artificial delta splay cuts, one of several techniques being applied to marsh restoration, creation, and management in coastal Louisiana. Methods of engineering analysis available to aid in design and to evaluate the effectiveness of the technique are described.

BACKGROUND: The majority of the coastal region of Louisiana has been built from deltaic deposits of the Mississippi River, with the river changing its primary course numerous times over the past several thousand years. These long-term deltaic processes involve a natural growth and decay cycle for each subdelta. In recent years, major portions of coastal Louisiana have experienced significant declines in subaerial land as individual older deltaic deposits enter the decay portion of the deltaic cycle. The loss of coastal Louisiana wetlands has been dramatic for several decades, with 1,526 square miles (>3,950 km^2) of wetland lost over the period 1930-1990 (Boesch and others 1994). With 40 percent of the total coastal wetlands of the United States in Louisiana, those losses account for 40 percent of the U.S. losses of coastal wetlands. The current annual loss is approximately 65 km^2 per year (Boesch and others 1994).

The impact of man on the modern Mississippi River delta has been demonstrated over the past century. Cubit's Gap subdelta was initiated in 1862 when a flood enlarged a ditch dug by the daughters of Cubit, an oyster fisherman. A natural crevasse developed that evolved into a major subdelta. Such accidental experiences have inspired the utilization of delta crevasse splay cuts as a viable engineering technique in marsh management in the lower Mississippi River delta complex. That technique is the subject of this technical note.

DELTAIC PROCESSES: The natural deltaic process can be summarized as a series of characteristic events (LeBlanc 1989): rerouting of a river or major distributary channel, prodelta clay deposition, increased sand arrival, channel shoaling, channel bifurcation, subaerial land emergence, vegetative stabilization, channel incising, channel elongation, continued bifurcation, delta lobe migration, diminished channel capacity, channel rerouting, reduced sediment supply, subsidence, and loss of subaerial land. The process continues in another location. The overall Mississippi River delta has been created by a series of channel diversions, subdelta formations and subdelta decay. These processes occur at a variety of spatial and temporal scales (Kolb and Van Lopik 1966).

DELTA SPLAY CUTS: The use of delta crevasse splay cuts involves opportunistic channel rerouting to control the overall location of small-scale subdelta growth. The technique has been pioneered by the Louisiana Department of Natural Resources and the Louisiana Department of Wildlife and Fisheries in partnership with National Fish and Wildlife Foundation, North American Wetlands Conservation Act, and the U.S. Fish and Wildlife Service. The process is started by the excavation of a small crevasse channel through the natural levee of a large pass within the delta. Material from the excavation of the shallow channel is mounded along the side of the channel to provide further steering of the water and sediments as well as shelter from wave activity. The conceptual design is shown in Figure 1. The crevasse cut provides a pathway to open water with a favorable gradient in water surface. The depth of the cut varies from 15 ft (4.6 m) at the main pass to 2 ft (0.7 m) at the end of the channel cut. As the river discharge in the primary distributary channel increases, natural forces will favor the cut, which will naturally enlarge.

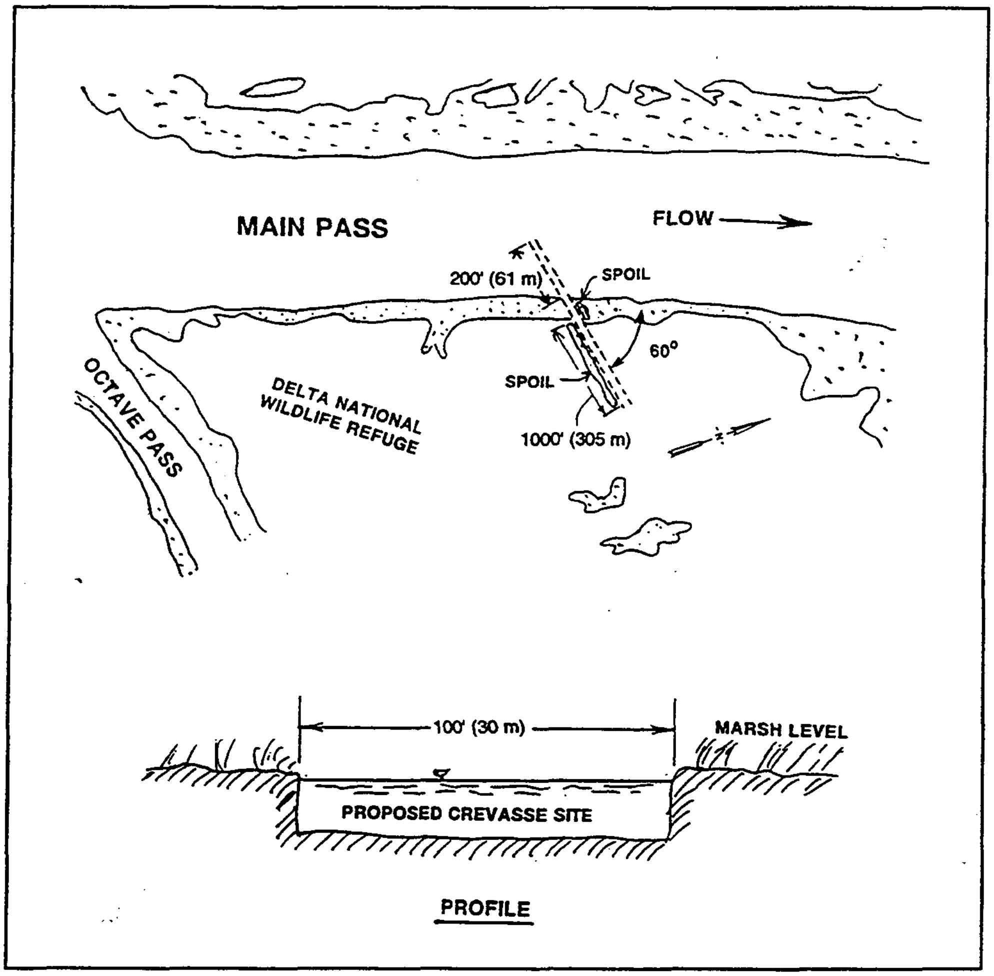

Figure 1. Example design of Delta splay cut

The enlarged crevasse cut begins to supply fresh water and sediment into the wetland selected for creation. The diversion develops a small subdelta covering several square miles. With time the subdelta splay develops its own series of distributary channels. As these channels elongate, the frictional resistance reduces the hydraulic efficiency of the channels, which will eventually close off naturally. The splay cut crevasses are expected to be active for about 5 years. After one delta splay has become ineffective at delivering sediment and water, another delta splay cut will be made in the delta. This activity can be maintained over a number of years, keeping several delta splays active at any time. The long-term plan for delta splay cuts is shown in Figure 2. The stability of the emerging delta splays is further enhanced by the construction of sediment fences. The plan is expected to create approximately 5,000 acres (20 km^2) over the next 50 years.

The number of active delta splay cuts is limited. The local enhancement of wetland creation cannot interfere with other deltaic activity in the delta. Excessive diversion of sediments and water would lead to loss of navigable depths in Southwest Pass because of the reduced sediment transport capacity in the main passes of the delta.

ENGINEERING ANALYSIS: The design of the cut involves determining the width, depth, length, and orientation of the cut. The channel should be designed to enhance natural erosion and enlargement of the

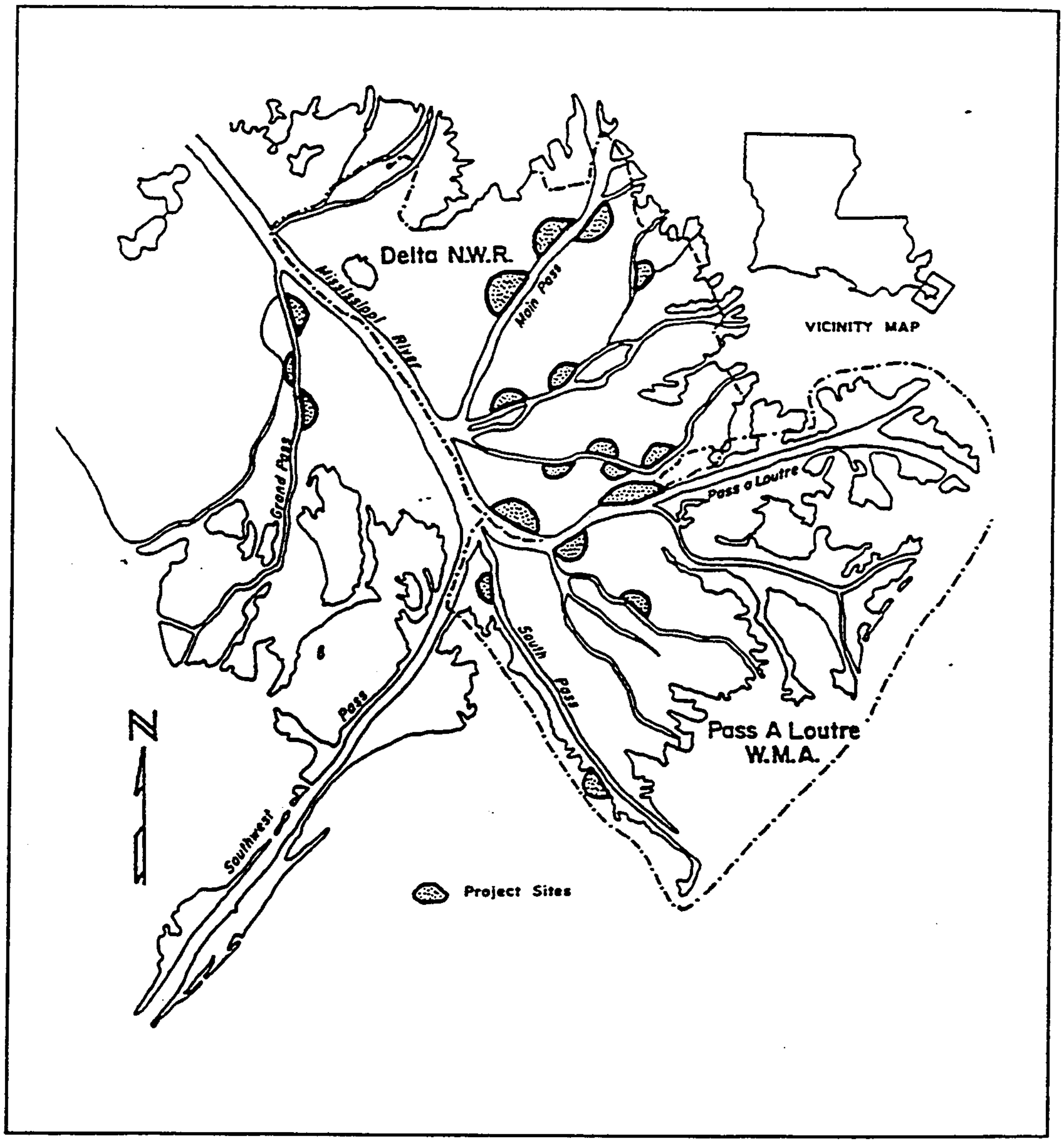

Figure 2. Delta splay cuts planned

cut, after which the natural deltaic processes will take over. The orientation of the cuts has been set to match the orientations of natural bifurcations within the delta, approximately 60 deg. The size of the cut can be designed based on hydraulic analysis of the flows through the original cut. The focus of the design is the shear stresses occurring in the crevasse relative to the erodibility of the sediments. The current velocity in the cut, V_c, can be estimated from application of the Bernoulli equation as

$$V_c = \left[\frac{2g\left(\Delta H + \frac{V_0^2}{2g}\right)}{\left(1 + h_e + h_f\right)} \right]^{1/2} \tag{1}$$

where

g = gravitational constant

ΔH = head difference across the cut

V_0 = main pass current

h_e, h_f = head loss coefficients for the entrance, exit, change in direction and friction

The current velocity in the main pass can be calculated from the discharge and geometry of the pass or is based on measurements. The design of the initial cut is incorporated in the head loss terms. The effective entrance and exit losses are reduced as the width of the cut is enlarged.

$$h_e = \frac{h_{e0}}{W}\left(1 + \frac{\alpha}{W}\right) + h_b \tag{2}$$

$$h_b = 0.001\ \theta \tag{3}$$

The frictional losses vary with the depth and length of the cut (Brater and King 1976).

$$h_f = \frac{29.1\ n^2 L}{D^{4/3}} \tag{4}$$

where W, D, and L are the width, depth, and length, of the cut, respectively, and n is the Manning's friction coefficient. The value of h_{e0} (Eq. 2) defines the overall smoothness of the basic cut through the bank line. The term α provides for the nonlinearity of the response with width of cut. The head loss associated with changing flow direction, h_b, is dependent on the overall change in direction, θ, expressed in degrees. For a crevasse cut at 60 deg, h_b would be 0.06, a loss factor applied to the velocity head.

The predicted velocity in the crevasse cut can then be used to estimate the bottom shear stress as

$$\tau_0 = \rho\ g\ \frac{n^2\ V_c^2}{(1.49)^2 D^{1/3}} \tag{5}$$

This shear stress is the stress immediately following the crevasse cut. This stress is then compared to the erosion resistance of the bank and bed material of the cut to determine at what flow level the cut will begin to enlarge. As the cut enlarges, the same analysis may be used to estimate the maximum size of the crevasse. The erosion resistance of the bed will define the flood level for which the crevasse will enlarge, given a fixed initial cut design. It may also define how long it will take to reach maximum dimensions. Therefore, it is critical to define the strength of the material in the flanks of the cut.

This analytical evaluation of the control section of the delta splay cut assumes that the cut does not dramatically change the hydraulic conditions in the parent distributary channel. That is, there is no significant reduction in the water surface elevation at the head of the cut because of the reduced discharge in the parent channel. If that assumption is invalid, a numerical analysis must be performed.

NUMERICAL MODEL: Deltaic marsh creation within the Mississippi Delta must be moderated to ensure that localized benefits will not cause loss of wetland in other portions of the delta because of shifting sediment supplies. The best means of evaluating the global deltaic integrity is through comprehensive numerical analysis. For this demonstration project a comprehensive numerical model of the Mississippi River delta was developed to illustrate the value of global evaluation. The model includes the entire delta (Figure 3) below Venice, LA. The modeling system TABS-MD, developed by the Corps of Engineers, was used (Thomas and McAnally 1990). The hydrodynamic model RMA-2 computes water levels and flows using a finite-element method to obtain an approximate solution to the Reynolds form of the Navier-Stokes equations.

The sediment transport model STUDH solves the convection-diffusion equation for total load transport with bed exchange using flow velocities and depths from RMA-2. RMA-2 was originally developed under contract by Resource Management Associates (RMA) of Suisun City, CA, and modified by the Waterways Experiment Station (WES) for use in the TABS-MD system. STUDH was jointly developed by WES and RMA. The modeling approach includes a method of describing the geometry of the wetlands statistically over subelemental spatial scales (Roig 1995). The technique, often referred to as marsh porosity by Corps modelers, allows for incorporation of the effects of the myriad of small tidal channels without their being explicitly resolved in the mesh.

The model was run for a range of river discharges and gulf levels to evaluate the response of the flow distributions to the distributary passes. Flow distributions to the major passes are presented for model and field observations (Copeland and Thomas 1992) in Figure 4. The current velocity patterns for the vicinity of Cubits Gap and the Head of Passes are shown in Figure 5. The response of the flow distribution in the numerical model to river discharge and gulf levels is shown in Figure 6 for Southwest Pass (at Head of Passes). The model provides a tool for evaluating the global effect of each of the delta splay cuts.

The hydrodynamic results were then used to drive the sediment transport model, STUDH, of the TABS-MD system to demonstrate the deposition patterns over the entire delta. An example of the suspended sediment field for a simulation of clay sediments with a river discharge below Venice of 500,000 cfs (14,160 m^3/sec) is shown in Figure 7. The associated deposition pattern for that flow is presented in Figure 8. The deposition patterns for the simulation show the majority of deposition occurring in the shallow back bay zones adjacent to the secondary distributary channels. The patterns show a lesser degree of deposition in the shallows near the primary bifurcations, with greater deposition near the ends of the main passes. This observation supports the placement of delta splay cuts closer to the upstream ends of each of the passes, as shown in Figure 2.

DELTA MANAGEMENT: The management of the sediment and water resources reaching Louisiana coastal wetlands requires the integration of field experience with a regional analysis. A complex relationship exists between natural deltaic activity and the activity of man. The tools described here provide a means for design and analysis of wetland creation and management activities. The numerical simulation of alternative locations for management efforts can lead to optimization of those resources.

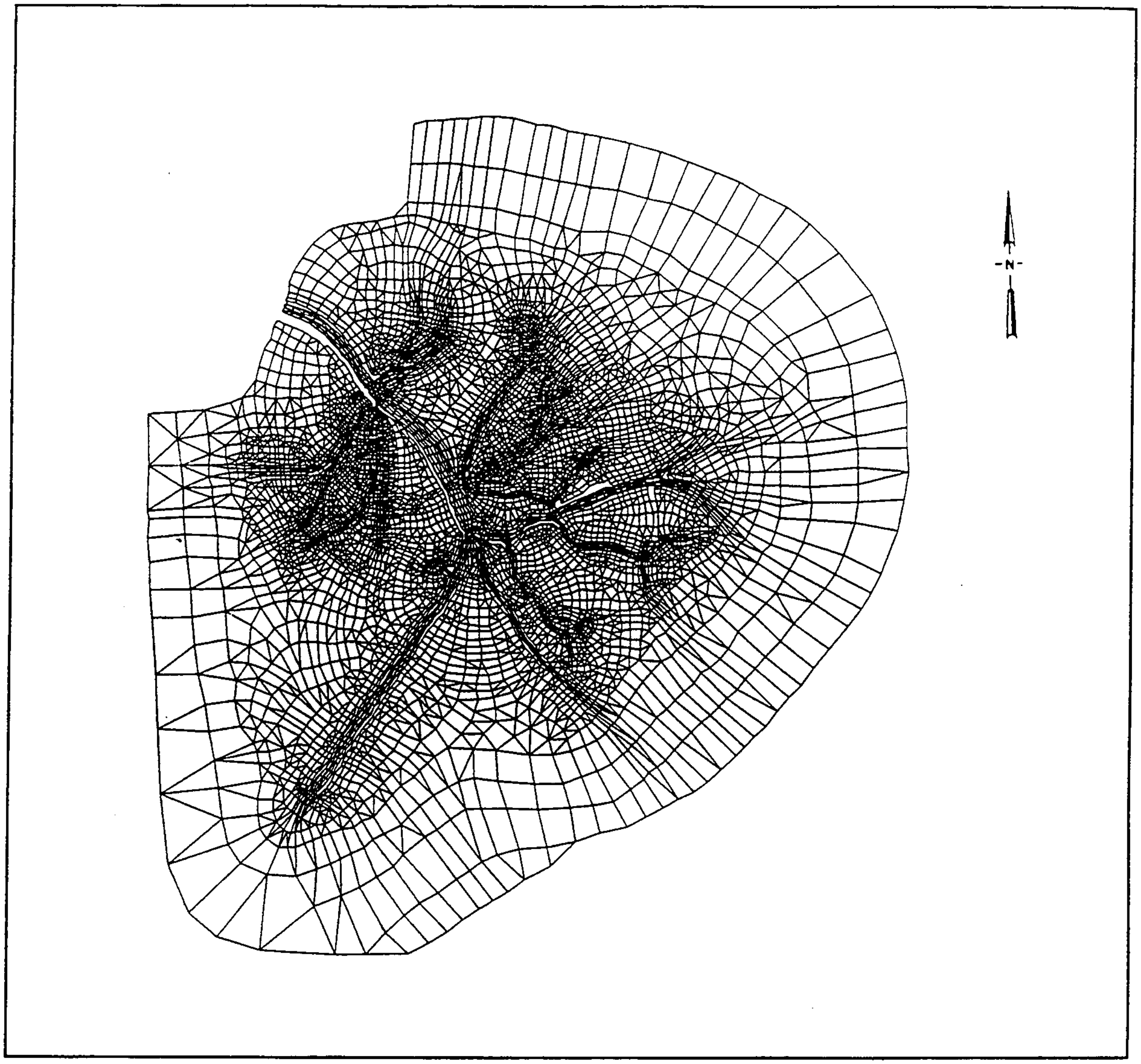

Figure 3. Computational mesh for numerical model

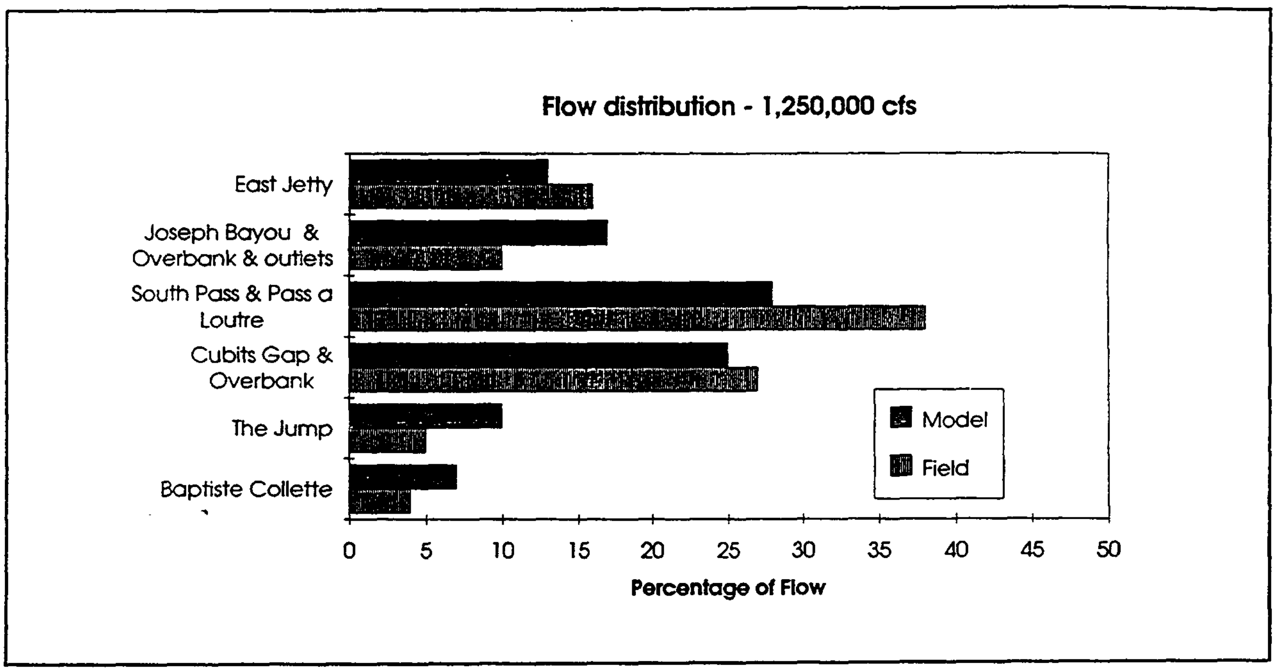

Figure 4. Comparison of model and observed flow distribution

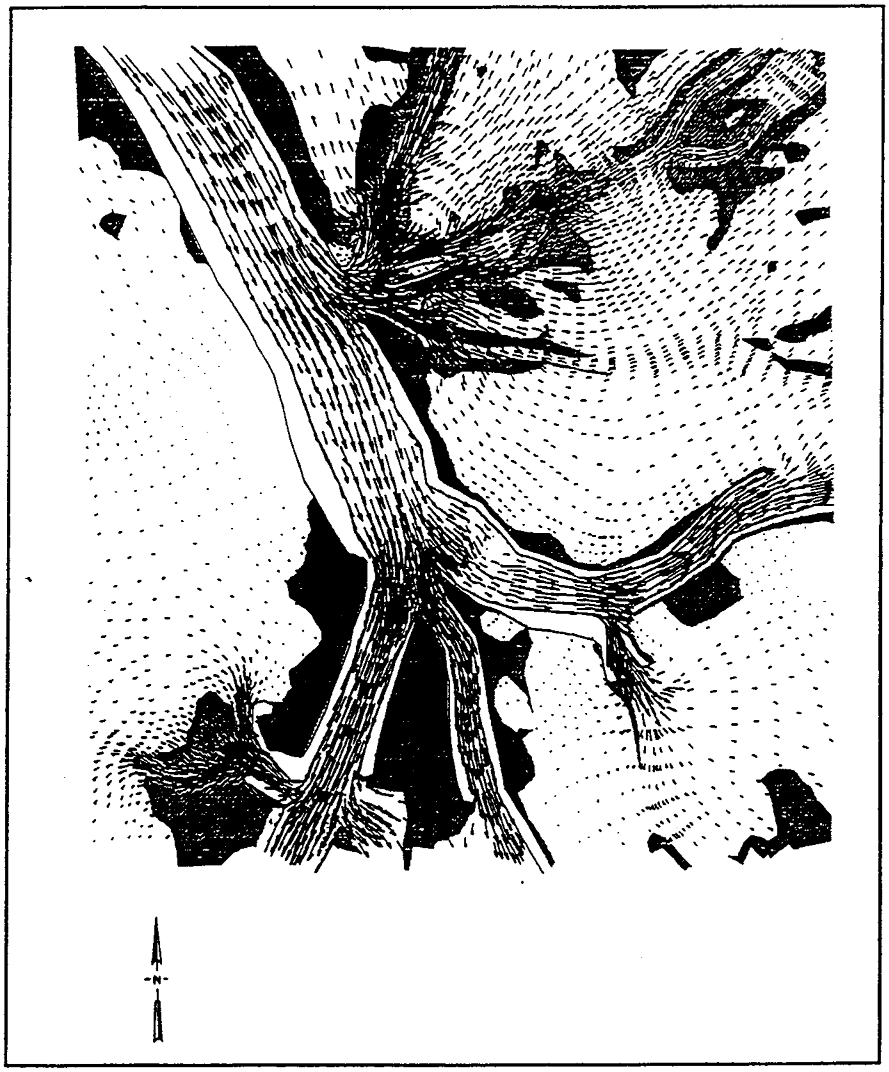

Figure 5. Current velocity patterns near Head of Passes

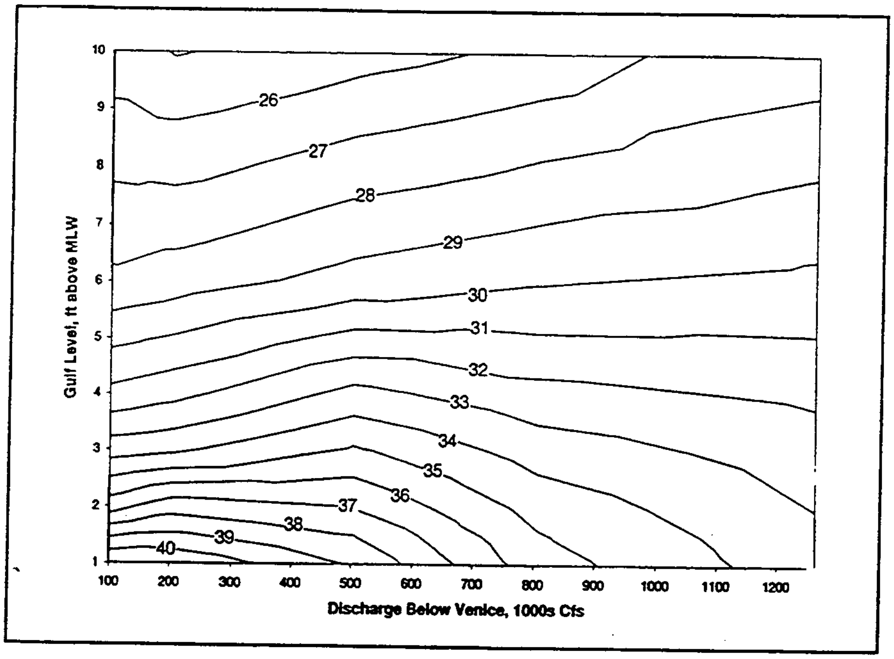

Figure 6. Percentage of flow at Venice entering Southwest Pass as a function of discharge and gulf level

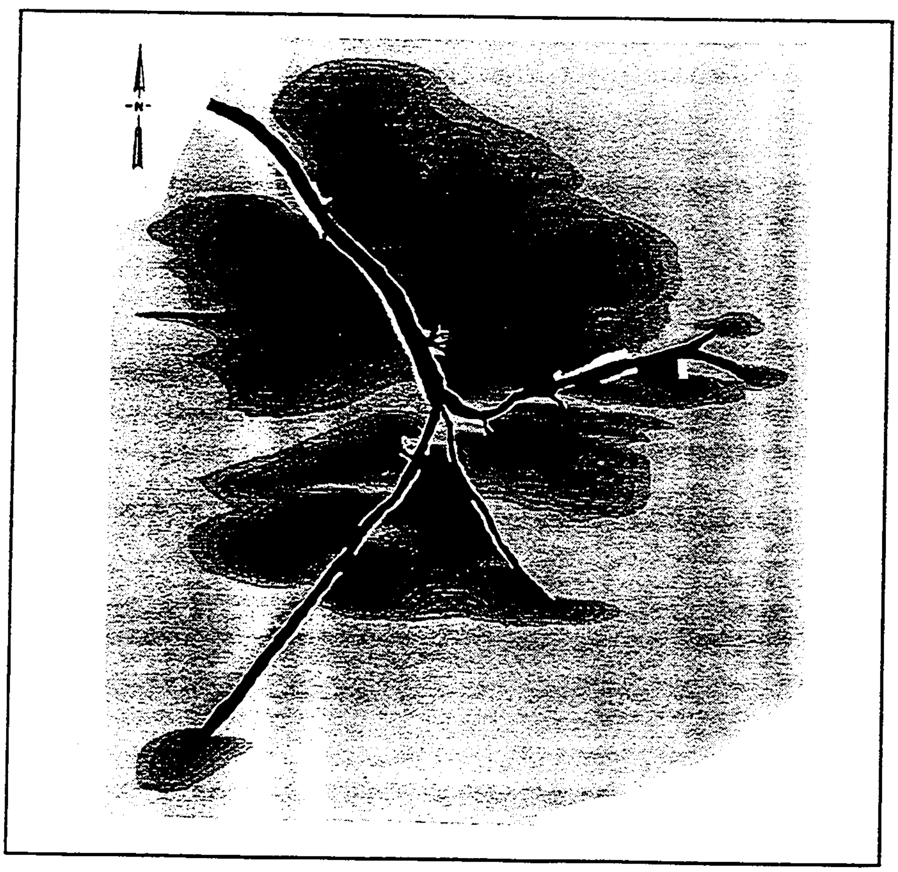

Figure 7. Sediment transport model concentration field

Figure 8. Deposition pattern from sediment transport model

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POINT OF CONTACT FOR ADDITIONAL INFORMATION: Mr. Joseph V. Letter, Jr., U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-HW-E, 3909 Halls Ferry Road, Vicksburg, MS, 39180-6199, phone: (601) 634-2845, author.

Wetland Engineering in Coastal Louisiana: Naomi Siphon

PURPOSE: This technical note describes a demonstration project for evaluating wetland restoration designs in coastal Louisiana. The goal of the demonstration project was to provide general insight into an alternative method for engineering creation and/or restoration of wetlands. Siphons are used to draw water and sediment from the Mississippi River into wetland zones that have been cut off from the river by flood levees. Siphons may offer an alternative for restoration of degraded freshwater marsh by providing water to counteract saltwater intrusion and sediments to restore freshwater wetland that is being converted to brackish marsh, salt marsh, and open water due to regional subsidence.

BACKGROUND: The Naomi Siphon is located approximately 20 miles (32 km) below New Orleans on the west bank of the Mississippi River, as shown in Figure 1.

The wetlands of coastal Louisiana are the result of the interaction of the Mississippi River with the Gulf of Mexico. The lower Mississippi River has experienced several major changes in course over the past 7,000 years. The wetlands west of the current Mississippi River route to the Gulf have experienced dramatic rates of wetland conversion to open water in recent years (Britsch and Dunbar 1993, Dunbar and others 1992). This is due primarily to reduced sediment supply to the area and the effects of subsidence. Additionally, enlargement of open-water areas leads to greater saltwater intrusion, stressed freshwater vegetation, and increased erosion due to wave action (Boesch and others 1994).

The precise underlying contributions to and rates of subsidence are a matter of debate. Some investigators emphasize the natural processes of river deltas and view human activities as secondary. Others emphasize contemporary human intervention as the primary cause of subsidence (for example, oil and gas extraction). In any case, it is generally accepted that a decrease in supply of sediment to coastal Louisiana wetlands is a significant factor in the accelerated degradation being observed. It has been documented that a significant part of this decrease in sediment supply is due to soil conservation techniques in upstream watersheds and the effects of the levee system along the Mississippi River through Louisiana (Kesel 1988, 1989). The loss of coastal Louisiana wetlands has been dramatic for several decades. About 1,526 square miles (>3,950 km^2) of wetland loss has been documented over the period 1930-1990 (Boesch and others 1994). One author has calculated the current rate of loss of wetlands in the Barataria Basin at 2 percent per year (Britsch and Dunbar 1993). This compares with the 0.4 percent per year overall loss rate for the entire Mississippi Deltaic Plain.

CONCEPT OF SIPHON: The purpose of the Naomi Diversion Siphon is to divert water and associated nutrients and sediments from the Mississippi River as a means of wetland conservation and restoration. The diverted river water is routed into an area of adjacent marshes that have been rapidly deteriorating as a result of saltwater intrusion and subsidence (Wetland Conservation and Restoration Task Force 1990). The location of the siphon structure is near the community of Naomi in Plaquemines Parish. The marshes adjacent to the Mississippi River on the west side are part of the Barataria Bay system.

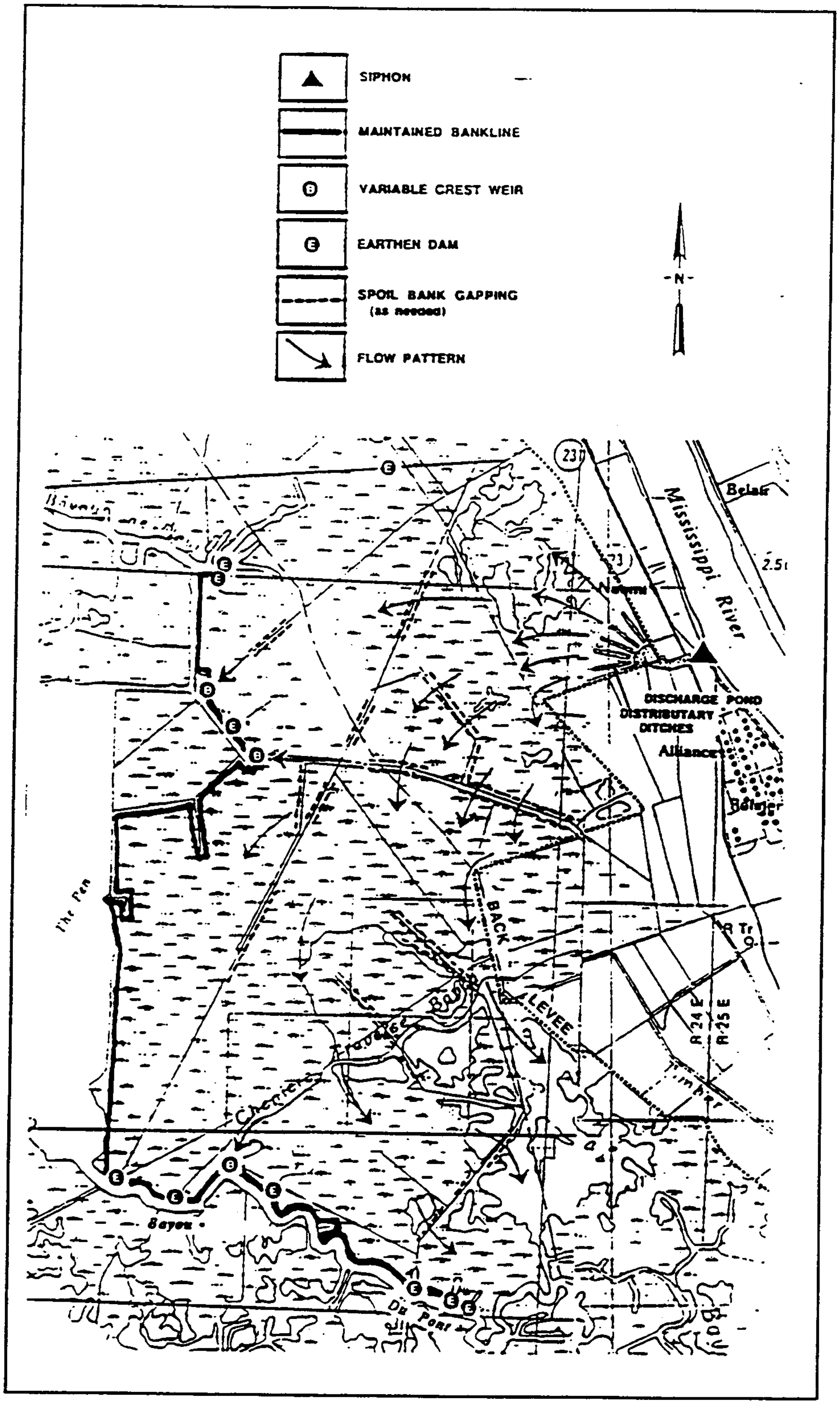

Figure 1. Site map showing location of Naomi Siphon

DESIGN OF SIPHON: The original siphon design called for eight 6-ft (1.8-m)-diameter pipes. These were constructed so as to route water from the river, over the river levee, under the roadways, and through a back protection levee to the marsh, a total distance of 2,750 ft (838 m). The design discharge for this battery of siphons is 2,400 cfs (68 m^3/sec) during the spring high water on the river. The original design documentation predicted that sediment deposition would be enhanced over an area of 8,200 acres (33 km^2) of marsh (Wetlands Conversation and Restoration Task Force 1990). The design called for an additional piping to increase the capacity to as much as 6,000 cfs (170 m^3/sec). Also, a continuous bank line was constructed along a nearby lake, The Pen, and along Bayou Dupont in an effort to guide the discharge southward toward the most severely deteriorated wetland areas. Several control weirs were also constructed to allow diversion of some of the flow to the west. The goal of the placement of the siphon structure and the containment structures is to increase the residence time of the diverted waters.

ENGINEERING EVALUATION: The design of the siphon structure from an environmental point of view becomes a problem of sizing the capacity of the project. In turn the sizing of the capacity of the structure will be constrained by the hydraulic conditions posed by the river in the form of the driving hydraulic head and its variability over a typical year. However, more important is the establishment of the size of the domain to be contained as the receiving basin for the diversion, as defined by the location of the auxiliary containment structures. Most important is the establishment of the expected response of the receiving basin, for the salinity regime and sedimentation environment. Simplistic techniques for estimating the response of the system often fall short because of the complexity of the geometry and driving forces. The technique demonstrated in this study was the development of a comprehensive numerical model of the entire Barataria Bay system capable of directly simulating the response to the Naomi Siphon within the surrounding wetlands. The numerical model demonstrates the ability to define the response zone of the basin in terms of salinity and sedimentation response as a function of the discharge of the siphon.

MODELING APPROACH: The TABS-MD numerical modeling system was used to compute water levels, flow velocities, and salinities over the finite-element mesh shown in Figure 2. The TABS-MD system is a U.S. Army Engineer system of two-dimensional (depth-integrated) numerical models and associated user interface programs (Thomas and McAnally 1990). These computer programs have been used successfully by the Corps and other investigators to model a wide variety of riverine and estuarine systems.

The hydrodynamic model RMA-2 computes water levels and flows using a finite-element method to obtain an approximate solution to the Reynolds form of the Navier-Stokes equations. The transport model RMA-4 solves the convection-diffusion equation for constituent transport using the same numerical method and employing flow velocities and depths from RMA-2. Both RMA-2 and RMA-4 were developed under contract by Resource Management Associates of Suisun City, CA, and modified by the Waterways Experiment Station for use in the TABS-MD system.

SIMULATION DESIGN: The development of the computational mesh for the study used information from a wide range of sources; topographic charts, land loss maps, navigation charts, and other data sources were compiled to define elevations over the system. This information was digitized and organized by 15-min quadrangle and provides a digital terrain map of the majority of lower coastal Louisiana for use in future studies.

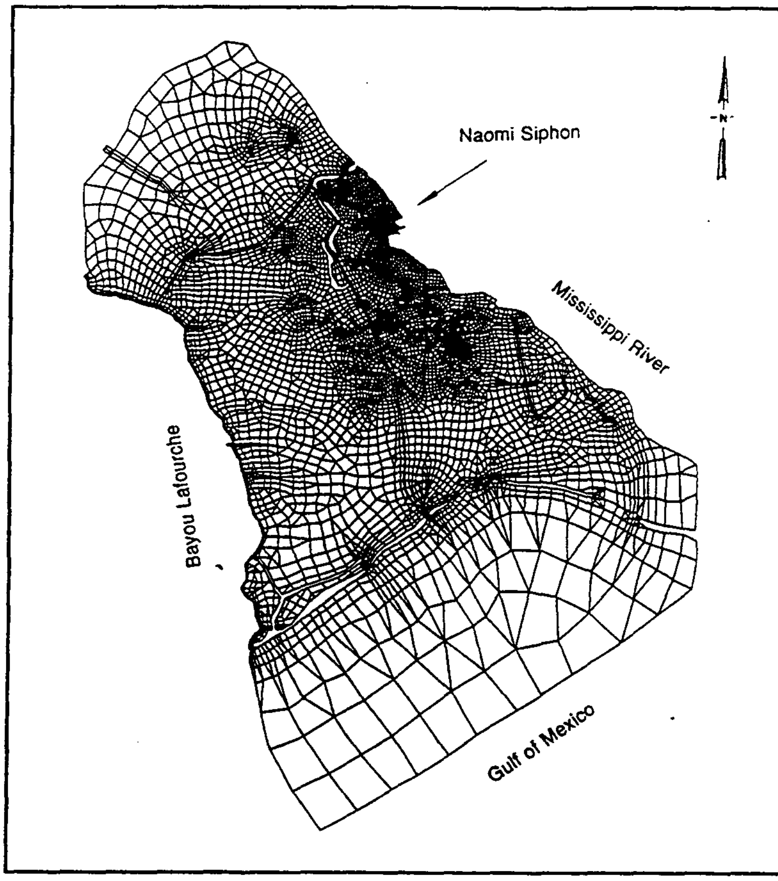

Figure 2. Finite-element mesh of Barataria basin

The computational mesh shown in Figure 2 was generated from these digital terrain maps with the extensive resolution needed to define the majority of significant channels through the Barataria Bay system. The mesh has 35,780 nodes and 12,591 elements. Even with this high level of resolution, the size of the system being modeled required that many features be schematized. The highest levels of resolution were assigned to the zone near the location of the siphon (see Figure 3). The modeling approach includes a method of describing the geometry of the wetlands statistically over subelemental spatial scales (Roig 1995). The technique, often referred to as marsh porosity by Corps modelers, allows for incorporation of the effects of the myriad of small tidal channels without their being explicitly resolved in the mesh.

The numerical model has the flexibility to apply any combination of boundary forcings appropriate. These include gulf tidal conditions, local rainfall, upstream runoff via Bayou Des Allemands, wind conditions, and siphon diversion flows, including a no-flow "existing" condition as a baseline for comparison of siphon diversion effects.

HYDRODYNAMIC RESPONSE: For the demonstration simulation, a repeating 2-ft (0.6-m) diurnal tide range was applied at the Gulf of Mexico boundary of the model. The inflow from Bayou Des Allemands at the northwestern boundary of the mesh was set to a typical value of 10,000 cfs (283 m^3/sec). A baseline simulation was made without any siphon diversion, and then siphon discharge simulations were performed with siphon flows of 2,400 and 6,000 cfs (68 and 170 m^3/sec). The modeling procedure was designed to evaluate the impact of the siphon diversion on the

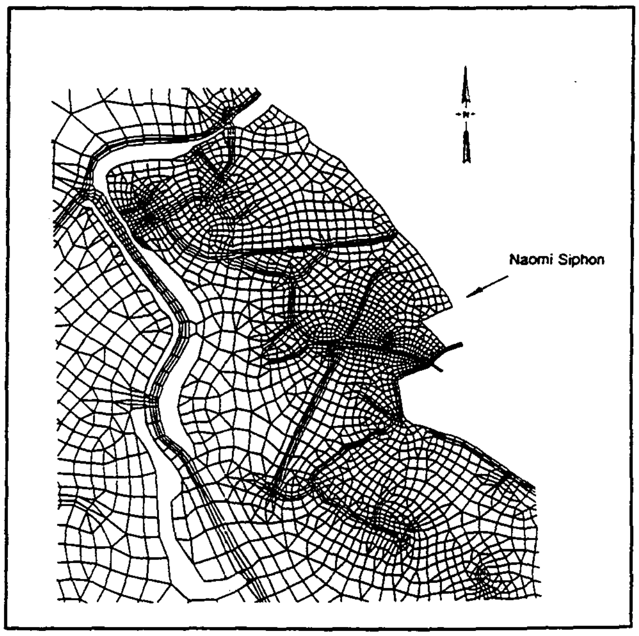

Figure 3. Inset of finite-element mesh showing location of Naomi Siphon

far field, and the model resolution was not included to address near-field detailed initial mixing at the point of discharge from the siphon pipes. Consequently, the diversion was modeled as a mass loading within a single element at the general siphon location.

The hydrodynamic response of the model matched the observed field behavior. The tide range is reduced significantly as the tides propagate up through the wetlands to as low as 0.5 ft (0.2 m) in Lake Salvador. The influence of the diversion siphon on current velocities is not readily visible except for immediately adjacent to the outlet location. When the siphon flows are incorporated within the baseline tidal flows, their influence is barely discernible. The barrier islands forming the southern side of Barataria Bay allow tidal incursion through only a limited number of inlets, resulting in the strongest tidal currents localized in those inlets. Figure 4 presents the currents in the vicinity of the barrier island inlets.

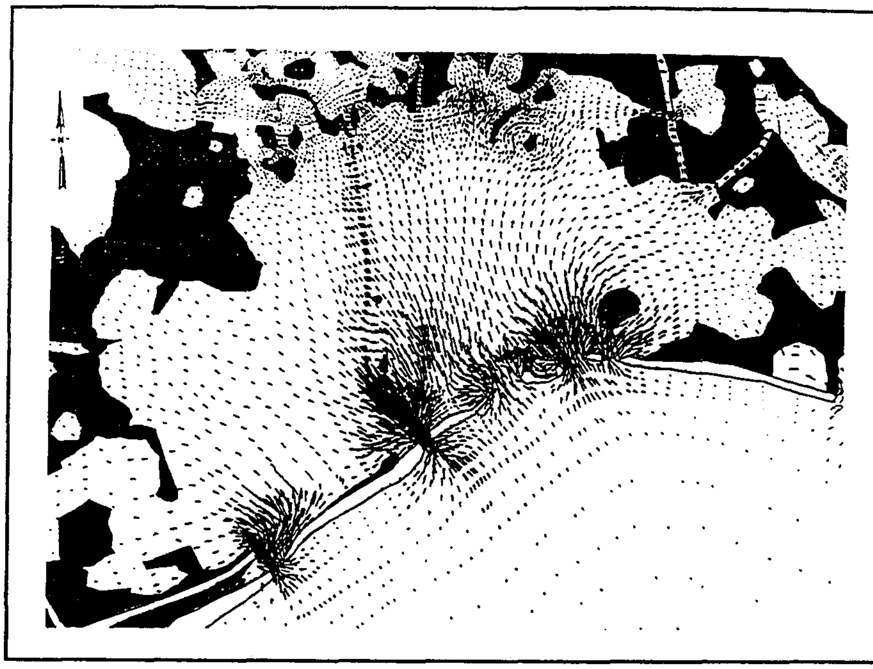

Figure 4. Peak flood currents in lower Barataria Bay

SALINITY RESPONSE: Salinity intrusion demonstration simulations were performed for each of the hydrodynamic conditions described above. The salinity simulations were performed using RMA-4 with the hydrodynamics provided from RMA-2, as described above. For all simulations, the same initial salinity distribution field was assigned to the system. That salinity distribution was derived from a limited amount of field salinity data, using the numerical model itself to interpolate the salinities over the entire computational mesh. As the individual simulations proceed, any subtle differences observed are directly associated with differences in the discharge level from the siphon.

As a baseline for comparison, Figure 5 shows the isohalines at hour 25 in the tidal cycle for the overall model with no diversion flow from the siphon. This salinity distribution was found to be a reasonable reproduction of that actually observed in the field. Figures 6 and 7 show the isohalines that result from modeling 2,400 cfs and 6,000 cfs diversions, respectively, through the siphon. Both of these figures show the salinity distribution predicted at hour 25 in the tidal cycle. These figures show isohalines in the vicinity of the siphon. The only difference between the conditions for the model runs illustrated in Figures 6 and 7 is that of the 2,400- versus 6,000-cfs diversion. The difference in isohaline patterns between these two simulations can therefore be attributed to the diversion alone.

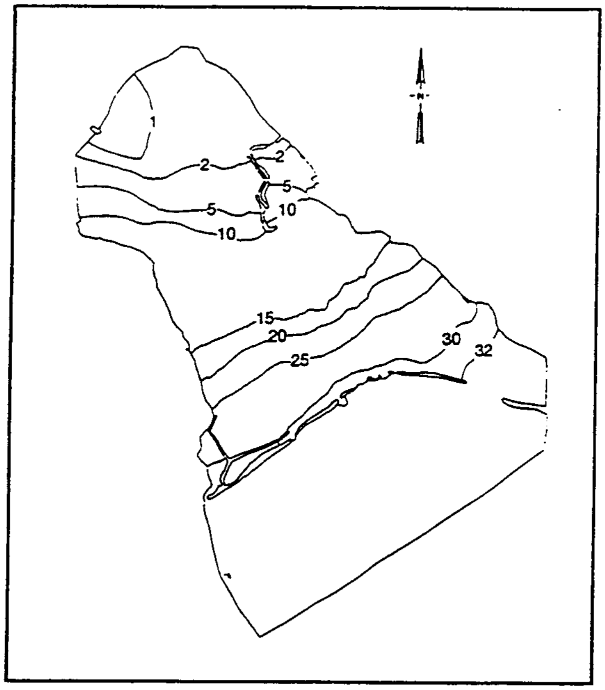

Figure 5. Isohalines in Barataria basin at hour 25 with no diversion

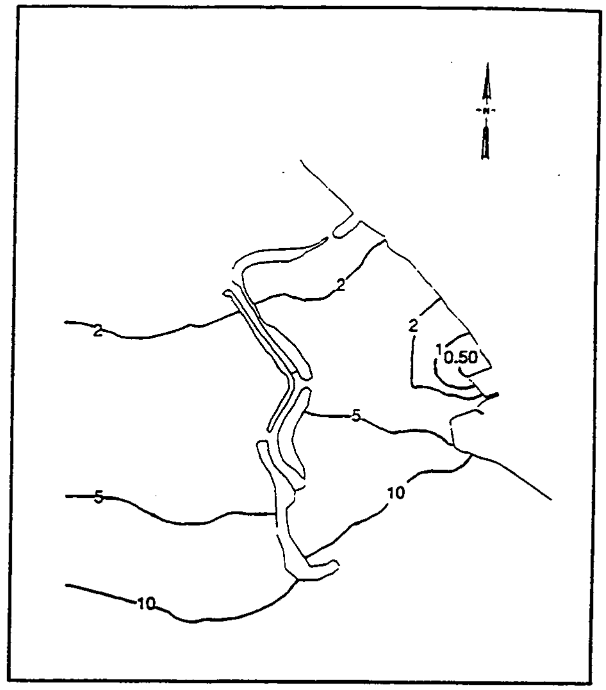

Figure 6. Isohalines in vicinity of Naomi Siphon at hour 25 (2,400 cfs)

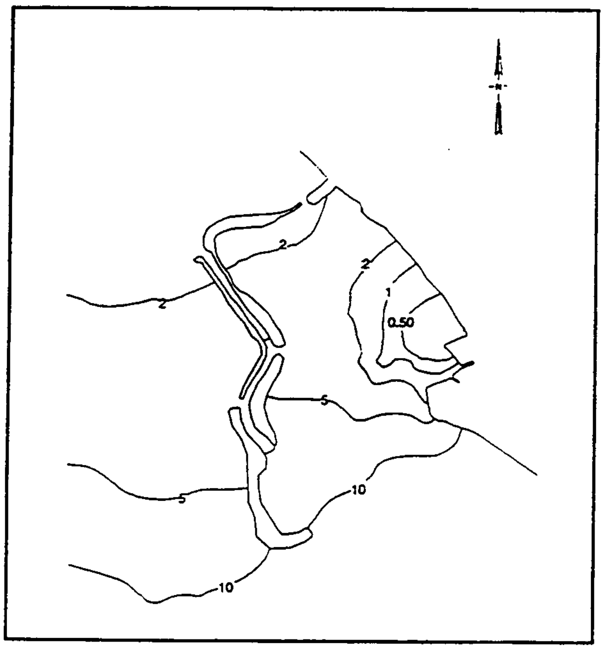

Figure 7. Isohalines in vicinity of Naomi Siphon at hour 25 (6,000 cfs)

The influence of the diversion on the salinity levels is very subtle, with progressive movement of the isohalines southward as the diversion flow is increased. The isohalines shown in Figure 6 indicate that the higher flow diversion is causing the water to become somewhat fresher in the vicinity of the siphon. These results illustrate the limited zone of significant influence of the specified diversion relative to the vast expanse of the Barataria Bay system and the magnitude of the problem faced for the basin as a whole.

CONCLUSIONS: The results of the simulations shown are reasonable. The figures show isohaline patterns that resemble what would be expected to occur in the vicinity of the freshwater discharge of the siphon. Specifically, the growth of the lower salinity area in the vicinity of the siphon suggests that the model is capturing the effect of the siphon with regard to local salinity reduction. It has been demonstrated that the numerical model has the potential to realistically simulate the hydraulic and salinity transport phenomena in Barataria Bay. Furthermore, the zone of influence of the siphon diversion on salinities seen in the limited simulations performed for this demonstration project supports the appropriateness of the surface area delineated for containment of the receiving basin for the diversion flows.

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WRP Technical Note WG-SW-2.1
May 1994

Remotely Sensed Data: Information for Monitoring Dynamic Wetland Systems

PURPOSE: Digital imagery (or digital data) acquired by commercial remote sensing satellites, combined with inexpensive PC-based image processing software provides an efficient and cost-effective capability/technique for monitoring changes to wetland systems. This paper describes some of the potential of this imagery as well as some of the limitations and difficulties inherent in the use of remotely sensed data. Differences between the types of imagery available are described as well as the types of techniques which may be employed to analyze/manipulate the imagery. An example application of the use of this imagery for routine change detection is described.

BACKGROUND: Since the 1972 launch of the first Landsat satellite, the earth's surface has been routinely monitored by sensors specifically designed to study the earth's natural resources. There have now been five Landsat satellites placed successfully in orbit, providing a nearly continuous archive of imagery over the United States. In 1986, the Landsat satellites were joined by the French SPOT series of satellites in their earth observing mission. As satellite imagery represents an effective way of studying large areas of the earth's surface, a great deal of attention has been directed toward using this imagery to map or monitor wetland systems. The Corps of Engineers Wetlands Research Program has published a bibliography of these efforts classifying them by wetland and sensor type (Lampman, 1992).

The use of digital imagery from space platforms has mainly been limited to research laboratories and universities due to the large amount of disk space required to handle the data, the cost of the hardware and software to manipulate the imagery, and the CPU-intensive nature of the algorithms required to extract information from the raw data. These limitations have, for the most part, been overcome by rapid advances in processor speed and the reduction in prices of computer equipment and image analysis software. A computer based on an Intel 80486 CPU, with a disk capacity of 500 megabytes or more and a tape drive or CD/ROM player is all that is required to load, display, and manipulate satellite imagery. Of course, the types of analyses conducted will depend on the software used and the level of expertise of the analyst.

Recently inexpensive software tools have become available which allow users with minimal experience in image processing techniques to load and display satellite imagery and to analyze these data in concert with data stored in a geographic information system (GIS) database. Nearly all the GIS software vendors now offer "query" software which allows users to load imagery, overlay GIS information which has been input in a full-blown GIS, and to output color hardcopy products. Also, imagery vendors have begun to provide an array of products from the raw imagery which make the data easier to use. For example, both EOSAT and SPOT have for some time provided imagery which has been geocorrected (or georeferenced) to a map projection (such as the Universal Transverse Mercator projection). This means that the data can immediately be incorporated into a GIS database and the user is relieved of this laborious task. SPOT Image Corporation has also developed a suite of products which reduce the amount and complexity of processing required of the end user and which help limit the amount of data which must be purchased to meet the needs of a project. For example, SPOT will provide data to match standard USGS map frames, including a 7.5 $\times$ 7.5 minute (Latitude/Longitude), 15 $\times$ 15 minute, or 30 $\times$ 30 minute map sheet, in any projection. Users can also opt to buy imagery by the square mile (for a project boundary) or by linear mile along a corridor (such as a river channel, highway, etc.) This means that users only have to purchase the imagery required for their specific application, and it is delivered in a format which can immediately be loaded into a GIS or "query" system. EOSAT also offers a number of options for purchasing less than a full image, including half and quarter scenes.

In the past, satellite data were usually furnished on large 9-track tapes. Nine-track tape drives are extremely expensive items, often costing more than the computers to which they are attached. Today, both SPOT and EOSAT offer data on 8mm tapes, and SPOT has recently begun distributing products on CD/ROM.

TYPES OF DATA AVAILABLE: This technical note only addresses data which are available from the Landsat and SPOT satellites. These satellites carry passive sensors which image the earth in the visible and infrared portions of the spectrum.

When discussing digital image data there are two types of resolution which must be considered: spatial and spectral. Spatial resolution deals with the size of each picture element (or pixel) in the image. The coarser the spatial resolution, the less detail will be visible in the imagery. Spectral resolution deals with the number and width of the portions of the spectrum imaged by the sensor. Most remote sensing instruments divide the spectrum into a number of sections and measure the radiation within each of these "bandwidths." By combining three of these sets of measurements it is possible to produce a true or false-color composite image. Multiple bands of image data are also useful for conducting statistical analyses using image processing software. Table 1 below lists the instruments that have flown on the Landsat and SPOT satellites and their respective characteristics.

Satellite	Sensor	Date	Spatial Resolution	Spectral Resolution
Landsat 1-5	MSS (Multispectral Scanner)	1972-Present	80 x 80 meters	4 channels (visible and near-infrared)
Landsat 4-5	TM (Thematic Mapper)	1982-Present	30 x 30 meters	7 channels (visible, near and middle infrared, and thermal
SPOT 1-3	Panchromatic	1986-Present	10 x 10 meters	1 channel (visible)
	HRV	1986-Present	20 x 20 meters	3 channels (visible, near-infrared)

TYPES OF ANALYSES WHICH CAN BE CONDUCTED: The types of analyses which can be conducted on imagery are many; essentially, they can be grouped into two types: manual interpretation (sometimes referred to as photointerpretation) or quantitative analysis. The types of analyses which are to be conducted on imagery will depend both on the capability of the software and the knowledge of the analyst. In short, information may either be extracted by manual methods or through extensive digital/image processing.

Often, a great deal of information can be gathered simply by analyzing imagery on a computer screen. For example, one can tell instantly whether or not an area has been cleared by simply "viewing" the data in black&white or as a false-color composite. For this simple type of application spatial resolution is much more important than spectral resolution and SPOT panchromatic data are probably the best choice. However, when using satellite imagery to produce a characterization of land-cover in an area, multispectral data are required and Landsat TM may be more useful (even though the spatial resolution is only 30 meters as compared to 10 meters for SPOT panchromatic data). Therefore, it is important to consider how the data will be used and what is to be extracted from the imagery.

Multispectral classification of satellite data makes use of the fact that different surface cover types reflect the sun's radiation differently within each of the portions of the spectrum which the sensors image. By analyzing the unique "signatures" of cover types with statistical analysis algorithms, it is possible to produce a land cover classification of an area. This type of analysis requires a good deal more knowledge by the analyst, as well as much more sophisticated (and expensive) software. Work under the Wetlands Research Program has shown that it is very difficult, if not impossible, to map wetlands with imagery alone, particularly when dealing with bottomland hardwood wetlands. However, land cover classifications of satellite imagery can be useful for analyzing changes in adjacent uplands. Multidate imagery (i.e. data acquired at different times) can improve the ability to discriminate between wetland cover types but it is often difficult to obtain imagery at the correct times of the year and processing of more than one data set increases the cost.

The true value of satellite imagery is recognized when the data are used in conjunction with other forms of geographic data in a GIS. Imagery data are easily integrated with GIS systems. For example, it is possible to store information related to the hydric properties of soils, National Wetlands Inventory (NWI) data, wetlands permit data and analyze these data with satellite imagery used as a backdrop. By analyzing multiple dates of satellite imagery it is possible to identify recently developed or cleared areas near potential wetlands. By overlaying hydric soils and the NWI data, it is possible to further determine the likelihood that the suspect areas were originally wetlands. The user can then overlay wetlands permit information and determine whether or not a permit was issued for development. The satellite imagery can be analyzed in a black&white mode or, if the data are multispectral, a false-color composite can be generated. This example use of satellite imagery is one which involves relatively little processing of the imagery by the end user, and can be accomplished with minimally priced software ($\approx$ \$300.00). The main effort involved in such applications is related to developing the digital databases and in purchasing the imagery data.

LIMITATIONS OF IMAGERY DATA: Although imagery data can be extremely useful for change detection and monitoring efforts, satellite data can also present a number of challenges. For example, it is often difficult to obtain an image over the area of interest during the desired timeframe. The revisit characteristics of the satellites, as well as the presence of cloud cover, can limit the availability of data. When change detection is being conducted, this is less of a problem as data from the archive is useful. However, the limitation is critical when data are required in a very specific timeframe; for example, when imagery must coincide with field data collection.

Other limitations arise from the spectral and spatial resolution of the data. The limited spatial resolution of Landsat TM and MSS data sometimes presents problems when the features studied are rather small (or narrow). Riparian wetlands often represent this type of problem. In change detection studies, it may also be difficult to detect minor intrusions into a wetland area ("nibbling"). The spectral resolution of satellite imagery often limits the ability to accurately detect more than a few wetland types and classes. However, some of these limitations are removed when the data are used with ancillary data in a GIS database. Recently the Federal Geographic Data Committee (FGDC) published a report addressing the application of satellite data for wetlands mapping and monitoring (FGDC Wetlands Subcommittee, 1992). This report outlines a number of benefits and limitations of satellite data as well as the experiences of a number of Federal agencies and other organizations in applying these data for wetland studies.

AN EXAMPLE OF A CHANGE DETECTION APPLICATION: The WES Environmental Laboratory has been involved in a major effort to characterize changes to the wetlands in the Cache River basin in Arkansas. As a part of this study, remote sensing data (Landsat) were acquired for multiple dates and these data were evaluated for monitoring the wetlands over the entire basin ($\approx$ 6 km $\times$ 20 km). Visual analysis techniques were employed as well as quantitative multispectral classification. It was often difficult to obtain data at the optimum date for classification, and frequently the best date for analyzing forest classes didn't coincide with the best date for analyzing agricultural patterns, marsh plant cover, etc. This meant that multiple dates of imagery were required to get the best results. Also, without the aid of soils information, a digital elevation model, and hydrography data it was difficult to consistently differentiate uplands forest areas from bottomland hardwood wetlands.

Some of the most exciting uses of imagery data were from simply analyzing the data in conjunction with the other in the contained data GIS. Areas of clearing, for example, were immediately identified. Figure 1 represents a portion of the NWI data for the Cache River basin. The large dark feature along the eastern portion of the basin is classified as a palustrine-forested wetland. However, in Figure 2, which is a black&white portrayal of a false-color composite, it is apparent that most of the area has been cleared. By analyzing previously acquired imagery of the area it was apparent that the area had been cleared between the time the aerial photography which was used to compile the NWI map was obtained and the time the satellite imagery data were obtained. The query software which was used to manipulate these data provided the ability to quickly overlay soils data to determine whether or not the soils in the area were hydric in nature and to display the hydrology of the area. By analyzing the basin in this manner it was possible to isolate errors both in the landcover classifications derived from the satellite imagery as well as in the NWI data. This type of quick, simple access to spatial data and the ability to get repeated, inexpensive snapshots of an area in the form of satellite imagery represents a powerful analysis and site monitoring tool.

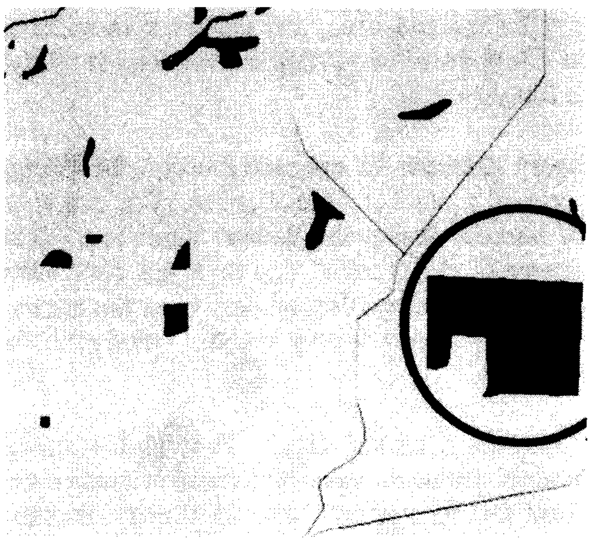

Figure 1. NWI data showing palustrine-forested wetland

Figure 2. Black and white image of false-color composite showing cleared forested area

RESULTS: Satellite imagery data together with image processing techniques represent a unique tool for monitoring wetlands. Recent developments in terms of software, hardware, and the availability of derived products have removed many of the limitations associated with effectively using remotely sensed data. Users should be cautious, however, when selecting imagery to be used for a specific application, carefully taking into account such things as the optimum date to analyze the features of interest, and the spatial and spectral characteristics of the sensors.

SOURCES FOR MORE INFORMATION: Both SPOT Image and EOSAT produce newsletters which describe the products offered as well as outline some of the applications of these data. Subscriptions to these newsletters are available free of cost and may be obtained by calling the telephone numbers listed below.

ADDRESSES AND PHONE NUMBERS OF IMAGERY SUPPLIERS:

EOSAT
4300 Forbes Boulevard
Lanham, MD 20706
(800)344-9933

SPOT Image Corporation
1897 Preston White Drive
Reston, VA 22091-4368
(703)715-3100

FOR MORE INFORMATION CONCERNING REMOTE SENSING APPLICATIONS WITHIN THE CORPS: The Corps of Engineers has establish a Remote Sensing/GIS Support Center to assist Corps district offices in the application of remote sensing technologies. The address is:

U.S. Army Cold Regions Research & Engineering Center
ATTN: Remote Sensing/GIS Support Center (CECRL-RSGISC)
72 Lyme Road
Hanover, NH 03755-1290
(603) 646-4372

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Lampman, J. L. 1992. "Bibliography of remote sensing techniques used in wetlands research," Technical Report WRP-SM-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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Differential Global Positioning System Techniques For Surveying/ Mapping within Forested Wetlands

PURPOSE: This technical note describes the use of Differential Global Positioning System (DGPS) techniques to locate sampling sites and to delineate sampling transects within bottomland hardwood (BLH) forested wetlands. DGPS positioning techniques provide biologists and field scientists with coordinate positions of sample sites throughout the world. A common misconception is that GPS will not provide positions inside a forested area (i.e. BLH). This technical note describes techniques used by scientists at the U.S. Army Engineer Waterways Experiment Station (WES) to provide reliable XY coordinate positions within a BLH forested wetland.

SURVEY TECHNIQUES: The Global Positioning System data collection techniques used for locating XY coordinate positions and mapping transect lines and boundaries within a BLH forested environment were primarily the same as those used outside the forested environment, with the exception of a few tailored operational and data processing steps. Some GPS radio signals do penetrate the forest canopy, and therefore reliable positions can be obtained using proper procedures and equipment. GPS positioning is dependent on the GPS receiver collecting and processing a usable signal from a minimum of three two-dimensional (2-D) or four three-dimensional (3-D) GPS satellites. At this time there are 26 operational satellites in orbit for use with GPS surveys. A reference receiver is required to collect positioning data simultaneously at a known location within 100-150 miles of the field position. Data collected from the fixed GPS receiver and positions collected by a roving GPS receiver allow post-processing to obtain differential GPS/DPGS positions which are more precise than those obtained using a single receiver.

Mapping grade GPS receivers are commonly only single frequency (L1) GPS receivers. These units receive only the course acquisition (C/A) code and are capable of computing the post-processed DGPS position to an accuracy within 2 to 5 m X-Y, and 4 to 10 m Z, or elevation. GPS receivers require a relatively unobstructed view of the sky (i.e. GPS satellites).

Many locations within a BLH forest are suitable for GPS reception using mapping grade receivers; however, the time spent at these locations is dependent upon good planning and proper field techniques which allow a suitable number of position observations to be recorded with the satellites. Most receivers can provide coordinate display for monitoring position and system performance as well as the total number of observations collected for a group point.

GPS PROCEDURES: A GPS demonstration project was conducted within the Cache River Basin, AR, to determine the position of sediment stations adjacent to a flagged transect line, to determine the azimuth of that line, and to record the relationship of established sampling sites for mammal, soils, vegetation, and sediment stations along each transect line. The transect was originally laid out with a compass and tape (Fig. 1), and trees were tagged every 60 m along the line.

In order to conduct a proper DGPS survey, several U.S. Geological Survey (USGS) control points were located within a 35-km radius of the area. These marks had published latitude, longitude, and elevation available. The WES field team deployed the 12 channel GPS reference receiver on a control point at the local airport for use during GPS data collection periods.

An L1, C/A code, 6 channel roving receiver was used for surveying the XY positions. The receiver was equipped with an external antenna, 10-m antenna cable, extendable range pole, and a data recorder capable of recording positions both as points, or as point features, allowing names and notes to be entered about each.

The receiver was set to the manufacturers recommendations concerning satellite elevation, Positional Dilution of Precision (PDOP), and 2-D/3-D mode switching. The L1 roving receiver was deployed and immediately began receiving information from six satellites, using the best four satellites for determining the current coordinate position. As field personnel entered the forest, where the tree foliage and branching interrupted some signals (Fig. 2), the unit began receiving signals from as few as three satellites while continuing to compute positions. As the team walked along the flagged path, points were recorded by computing positions every three seconds. An audible beep would sound as each ground position was logged. The receiver was allowed to automatically switch to the best combination of satellites to assure the tracking and recording of the best positions. The antenna was carried atop a 2-m extendable pole, and the pole held such that the antenna's orientation would allow signals to be received on the flat antenna plate inside the top cover. When satellite signal reception was interrupted due to dense foliage and heavy branching, the field party would pause or move slowly along the line until signal reception and recording was reobtained. The team collected both 2-D and 3-D satellite position data.

Figure 1. Location of transect line

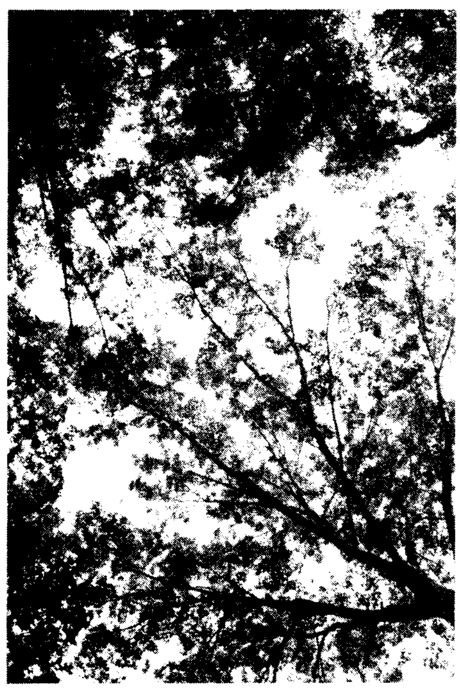

Figure 2. Foliage and branching structure

Four different transect lines were previously established within the Cache River forested wetland, each about 2 km in length. The DGPS survey results of one line, transect "C", are shown graphically in Figure 3. Figure 3a shows the 2079 corrected 2-D positions (3 satellites), plotted to determine the azimuth/orientation of the transect line. Figure 3b shows the line using 2094 corrected 3-D points (4 satellites). Figure 3c is a plot of 2-D and 3-D data used together (4173 points). If the best line is defined by calculating the mean, the deviation of the points from the calculated line was only 2-6 m, except for a few "extreme" 2-D points. After manual editing of the 2-D and 3-D data points, the resulting line was defined and is shown in Figure 4a. There was little accuracy advantage to using 3-D data alone, as the majority of the 2-D points were equally as reliable.

The positions of sediment sampling sites located adjacent to the transect line in the BLH forest were determined by acquiring GPS positions at stationary locations for three minutes, collecting data once per second. Again both 2-D and 3-D data were collected. The observations recorded at these seven sampling sites were later processed as group points, to determine the mean, and standard deviation for each site surveyed. These data are displayed in Figure 4b. The overall accuracy of an individual sampling site location (XY coordinate) was considered to be improved using this technique. The computed transect line with the mean position of the seven sediment sites is displayed in Figure 4c.

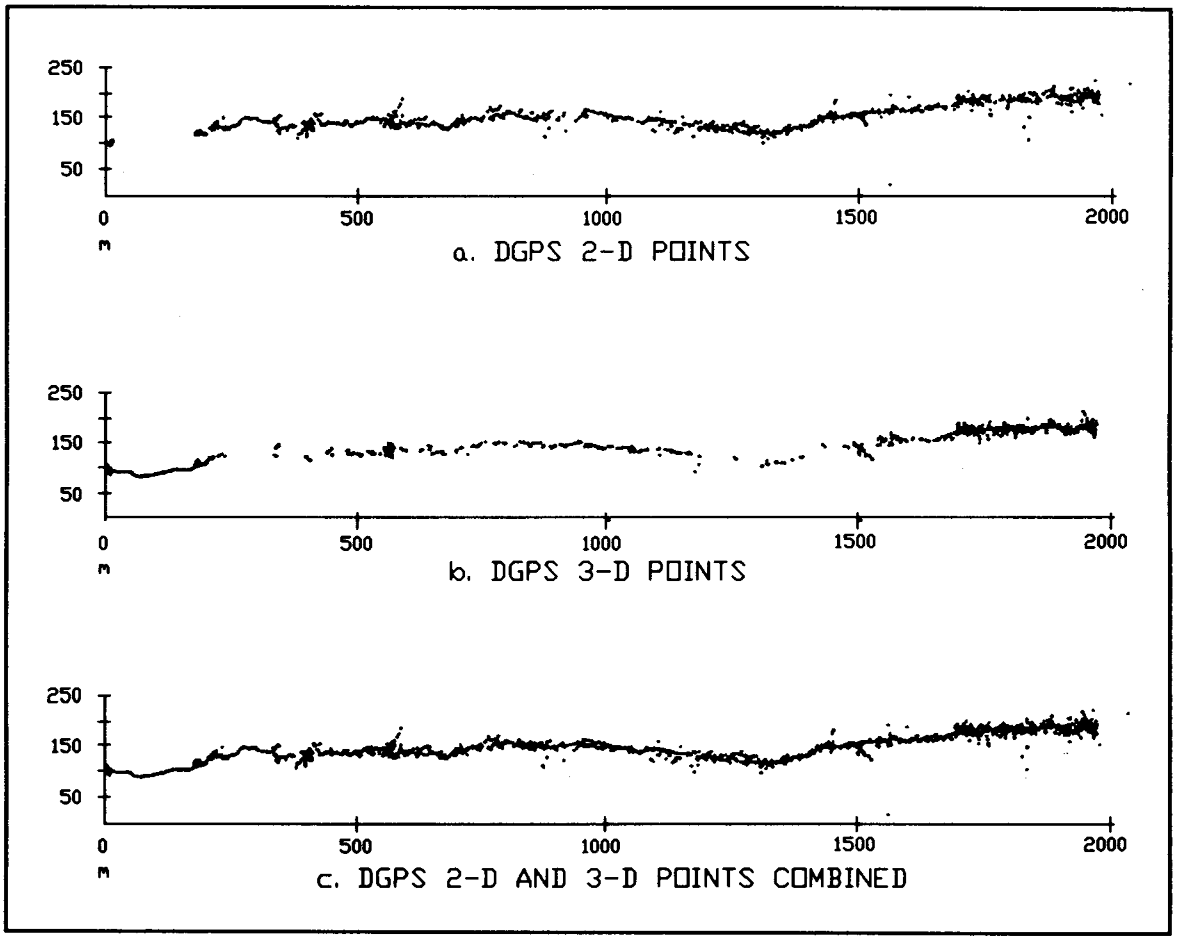

Figure 3. Raw DGPS data within the Cache River BLH forest

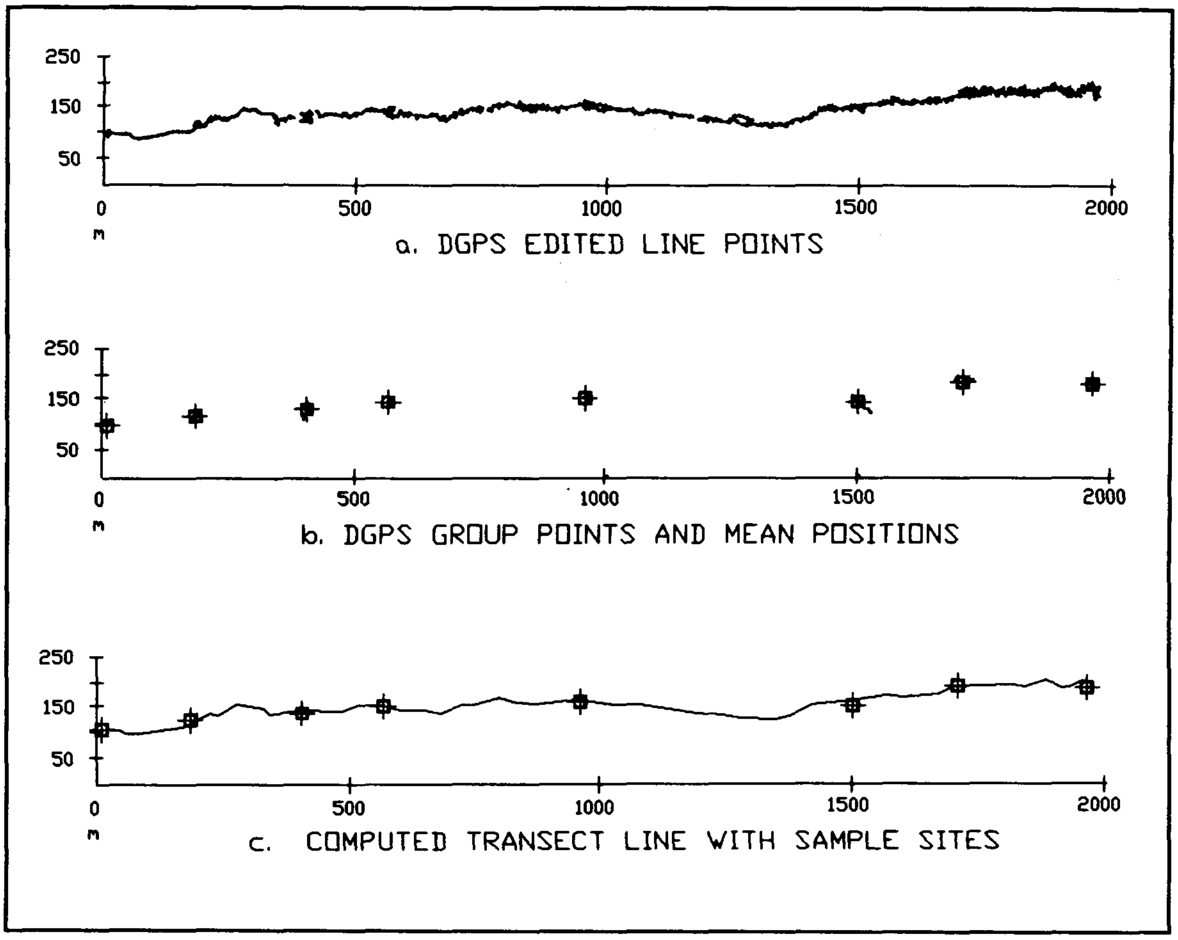

Figure 4. Edited DGPS data within the Cache River BLH forest

The sediment sites were located accurately with respect to the transect line as shown in Figure 4c. These reduced and edited transect line data are now suitable for transfer to a Geographic Information System (GIS) database system such as the one available for the Cache River Basin.

Elevation data (Z coordinates) could not be reliably obtained using DGPS techniques and as a result standard survey procedures were used to determine the elevation of the sediment sites.

CONCLUSIONS: GPS XY coordinate positions were obtained within a BLH forested wetland to an accuracy of approximately 2-6 m. However, GPS position data are best obtained by using the stationary site (group point) method, such as used for the sediment sites. A transect line is best defined by locating GPS positions or points every 50-75 m along the line.

If elevations within a BLH forest are required, monumented control points should be established by static DGPS methods outside the forest, at the beginning of each transect, and then the elevations transferred along the transect using traditional leveling techniques.

ADDITIONAL INFORMATION SOURCES:

USACE. 1991. NAVSTAR Global Positioning System Surveying. Engineer Manual EM 1110-1-1003. Washington, DC.

Trimble Navigation. 1991. TRIMVEC-PLUS® GPS Survey Software, User's Manual and Technical Reference Guide. Part Number 12351. Sunnyvale, CA: Trimble Navigation Ltd.

Trimble Navigation. 1992. General Reference, GPS Pathfinder® System. Part Number 18470-00. Sunnyvale, CA: Trimble Navigation Ltd.

Trimble Navigation. 1991. PFINDER® Software User's Guide. Part Number 18473-00. Sunnyvale, CA: Trimble Navigation Ltd.

ADDITIONAL INFORMATION ON GPS:

The U.S. Army Topographic Engineering Center (TEC), Fort Belvoir, Va. is conducting research on GPS methods/procedures, and additional information and list of publications may be obtained by contacting: Mr. Steven R. DeLoach, ATTN: CETEC-TL-SP, Fort Belvoir, VA 22060-5546. Phone (703) 355-3026.

Also, Office, Chief of Engineers, Directorate of Civil Works provides information of use of GPS Technologies to support broad mission areas. Point of contact is Moody K. Miles, III, ATTN: CECW-EP-S, Washington, DC. Phone (202) 272-8885.

POINT OF CONTACT FOR ADDITIONAL INFORMATION: Mr. Thomas E. Berry, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-EN-C, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, phone: (601) 634-3927, author.

WRP Technical Note WG-SW-2.3
May 1994

Hyperspectral Imagery: A New Tool For Wetlands Monitoring/Analyses

PURPOSE: This technical note describes the spectral and spatial characteristics of hyperspectral data and the potential application of these data for wetlands studies and monitoring applications. The advantages and disadvantages of these data for wetland evaluations are discussed. Spectral signatures extracted from data acquired by NASA's collected Airborne Visible/Infrared Imagery Spectrometer (AVIRIS) hyperspectral scanning over a wetland study site are analyzed.

BACKGROUND: Remote sensing technology is an important tool for exploring, monitoring, and analyzing wetland systems. Researchers have explored the use of digital imagery acquired from aircraft and spaceborne platforms for mapping wetlands and for analyzing changes to wetland systems (Lampman, 1992). However, traditional digital imagery from multispectral scanners is subject to limitations of spatial and spectral resolution.

- Spatial resolution refers to the size of individual picture elements or the area of the surface imaged in each of the square elements which compose the image. Spatial resolution is usually measured in meters. Typically, sensors such as the Thematic Mapper (TM) carried on the Landsat series of satellites have a spatial resolution of approximately 30 by 30 m. In other words, a feature must be fairly large and homogenous in nature in order to be detectable in an image.

- Spectral resolution refers to the number and width of the portions of the electromagnetic spectrum measured by a sensor. Multispectral scanners measure the radiation reflected by surface features in several portions of the spectrum and convert these analog measurements into digital counts, usually representing an 8-bit (0-255) range. By using statistical methods to analyze the distinct way in which different surface features reflect radiation in different parts of the spectrum, it is possible to characterize the surface features which make up an area. When the radiation reflected by a surface feature is only measured in 4-10 broad portions of the spectrum (which is typical of traditional multispectral sensors), it is sometimes difficult to differentiate between surface cover types which are similar in nature (such as wetland flora), or to detect subtle changes in the cover types of interest. The broad nature of the spectral wavebands acts to mask the subtle differences in spectral response of like cover types. When the spectral and spatial limitations of multispectral scanners are considered in concert, one can begin to appreciate the difficulties in using data from these sensors for mapping and analyzing areas as complex as wetlands.

A new type of remote sensing scanner is now being produced which, unlike multispectral scanners, is capable of measuring up to 250 very narrow portions of the spectrum. The systems are referred to as "hyperspectral sensors." They promise to revolutionize the utility of remotely sensed data for mapping and monitoring wetlands by eliminating the prior limitations of spectral resolution. With hyperspectral sensors it may be possible to map individual wetland plant species, as well as to detect very subtle changes in wetland systems, such as early signs of stress. Despite the great promise they offer, these sensors also introduce a suite of problems which must be addressed before it will be possible to routinely use these data for wetland applications.

Hyperspectral scanners collect large amounts of data, even when imaging a relatively small area at a coarse spatial resolution. For example, if the spatial resolution of a hyperspectral image is 20 by 20 m, and an area of 10,000 by 10,000 m is imaged, the resulting data requires approximately 150 megabytes of disk storage space. The same area imaged with a 2-m effective resolution would yield an image 11 gigabytes in size. Each 20 by 20 m image pixel in the above example would have approximately 220 associated spectral values. The volume of data makes it difficult to extract useful information. Statistical analysis techniques commonly used to process multispectral data are not suited to the amount and dimensionality of data present in a hyperspectral image. The problems encountered in processing hyperspectral data are, in some ways, similar to those experienced in the 1960s with the advent of multispectral data. The volume of data and the CPU-intensive algorithms which were required to extract information from multispectral data presented a challenge to computers of the time. Likewise, the amount of data collected by hyperspectral sensors represents a challenge to today's vastly improved computers.

AVIRIS APPLICATION: To examine the potential future applicability of hyperspectral techniques for monitoring wetlands, an image obtained from the AVIRIS hyperspectral scanner was acquired over an area adjacent to Green Bay, WI. The spectral curves measured over three different wetland types were examined. By viewing the high resolution spectral curves measured by the sensor over similar cover types in concert, it was possible to determine whether or not hyperspectral scanners like AVIRIS offer promise as future tools for routinely monitoring wetlands.

- Study area. The Green Bay West Shores State Wildlife Area is located along the southwest corner of Green Bay. The principal study site was a small coastal wetland area just north of Green Bay, WI (Figure 1). Three different wetland types were selected from 1:24000 scale Wisconsin Wetlands Inventory (WWI) maps. The three wetland types chosen were: Emergent/wet meadow, narrow-leaved persistent, wet soil (E2K); forested, broad-leaved deciduous, wet soil (T3K); and scrub/shrub, broad-leaved deciduous, wet soil (S3K).

- The AVIRIS scanner: The AVIRIS scanner is an airborne precursor to the High Resolution Imaging Spectrometer (HIRIS), which NASA plans to launch into space as a component of the Earth Observation System (EOS) in the future. The EOS represents a part of NASA's Mission to Planet Earth initiative (Gao et al., 1993, Goetz et al., 1985). AVIRIS was developed to enable the scientific community to conduct investigations into the utility of hyperspectral scanners for applications prior to the launch of the HIRIS. By making AVIRIS data available to scientists in a wide range of fields, it is hoped that the development of data utilization methodologies will be hastened so that hyperspectral data from the spaceborne platform will be employed more effectively. The Jet Propulsion Laboratory (JPL) is responsible for maintaining and operating AVIRIS until the HIRIS is in orbit.

- WRP study. A four step approach was taken to perform an initial investigation into AVIRIS data and to determine if it could be used to delineate different wetlands types. These steps required a basic knowledge of image processing techniques to extract useful information from the data.

  First, the AVIRIS data were loaded from the source tape provided by NASA's Jet Propulsion Laboratory onto a workstation class computer. The imagery acquired over the study area required 145 MB of disk space and was composed of 224 spectral channels, with 16 bit, signed (including negative) values. The image processing software at the WES Environmental Laboratory could display, but not process, 16-bit, signed data. Therefore, it was necessary to rescale the data values into an 8-bit, unsigned range (0-255). The maximum number of channels handled simultaneously by most commercial software packages is 15 to 20. As a result of this limitation, it was necessary to divide the AVIRIS data into separate image files prior to processing.

The second step in processing the imagery was to georeference these data to a common base map (Fig. 1). When aircraft data are collected, the data are not referenced to any coordinate system, or map base; therefore, before an evaluation of the data's usefulness could be conducted, the data had to be referenced to some real world map projection. This allowed overlay vector data from the Wisconsin Wetland Inventory, which had been digitized into a geographic information system (GIS), to be overlayed onto the imagery. Data georeferencing was performed by locating identifiable ground control points which were visible on both the AVIRIS data and 1:24000 scale quad maps, and then resampling the image data using a cubic two-dimensional polynomial algorithm.

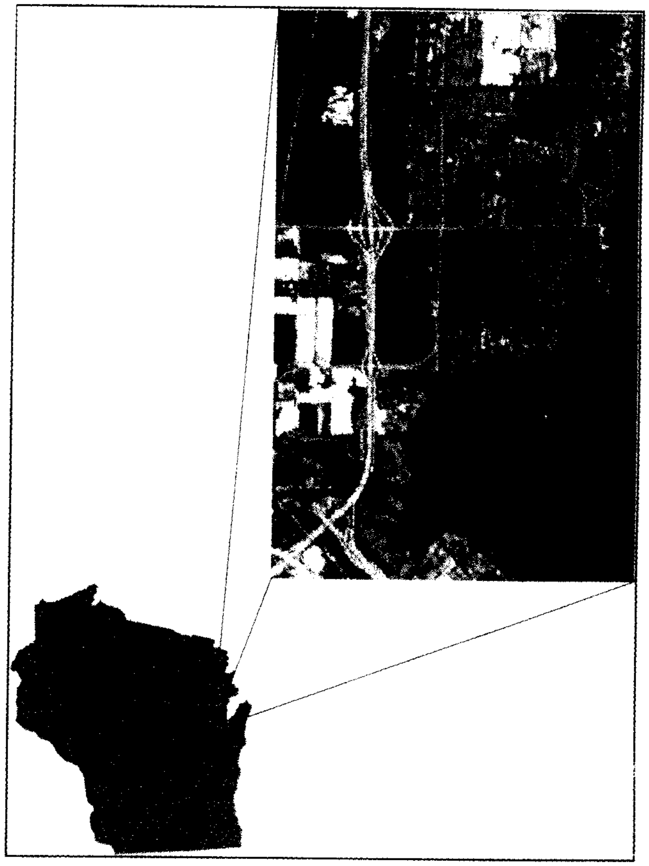

Figure 1. Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Data Acquired of the Green Bay, WI Area

The third step consisted of extracting spectral signatures for three different wetland types from the AVIRIS data. The areas of interest were defined by overlaying the Wisconsin Wetland Inventory vector data on the AVIRIS image and extracting homogenous pixels for each of the different polygon types. Four by four pixels blocks were then extracted from within the center of the polygon boundaries to insure that the pixels showed little or no variation in reflectance values and to insure that pixels selected were indeed the correct wetland type. Without taking this precaution, pixels along the polygon boundaries could inadvertently be selected. These boundary pixels could possibly have been indicative of a different wetland type or the result of a "mixed-pixel" effect. The sample extraction areas were then converted to vector format so that data could be extracted from the same areas for each of the 16-channel image files. In the fourth step, image statistics were generated for each of the three wetland types for all 224 channels, resulting in the spectral signatures presented in Figure 2.

- Preliminary results. At first glance, it appears that the three spectral curves presented in Figure 2 are quite similar. In a normal multispectral image, these three cover types would be almost impossible to distinguish, as the small differences which exist in certain portions of the spectrum would be masked by averaging effects. However, with the proper selection of bands (particularly in the near-infrared portion of the spectrum) and the appropriate algorithms, it should be possible to routinely delineate the three cover types of interest using hyperspectral data. These preliminary results indicate that phenological differences between even very similar wetland plant types can be effectively detected with hyperspectral data, but highlight the need for additional research into the use of hyperspectral data for monitoring wetlands.

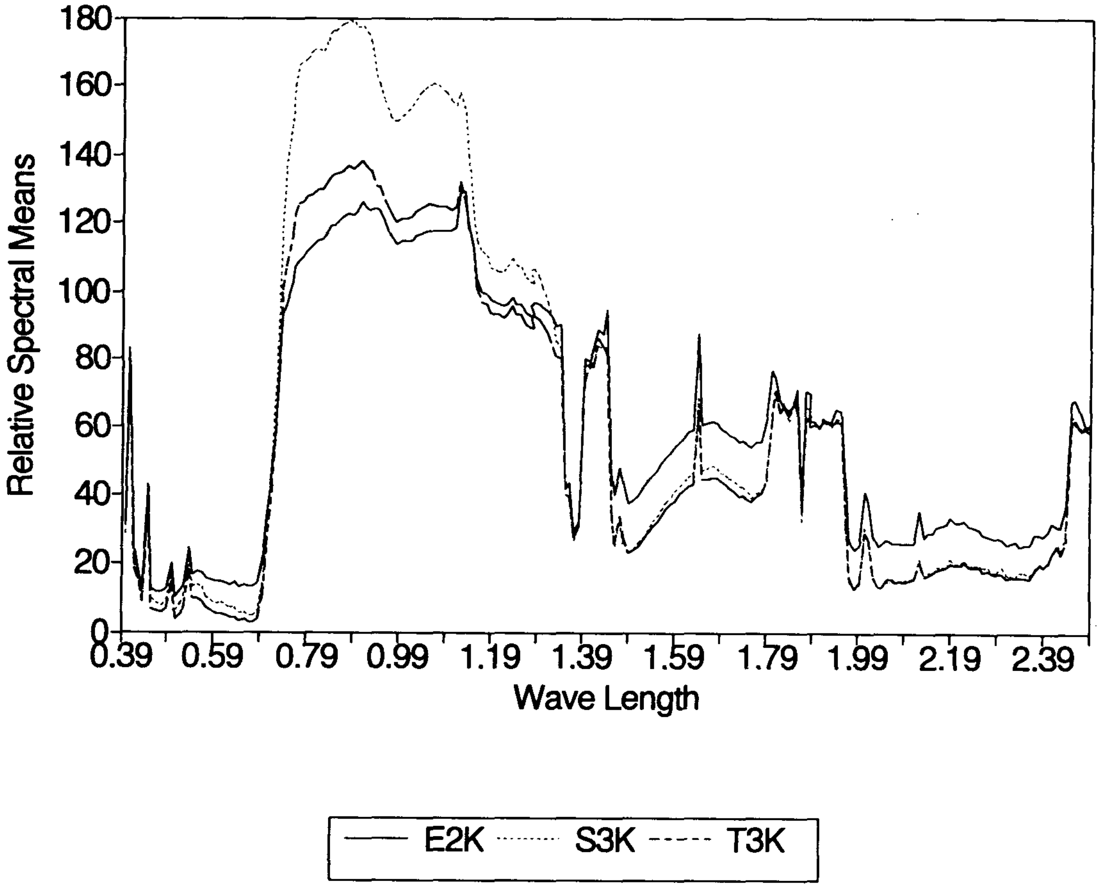

Figure 2. Spectral Means of the Three Wetlands Types

FUTURE DEVELOPMENT: Most of the limitations in using hyperspectral data arise, not from the data itself, but from the current state of the art in processing capability and knowledge of the spectral characteristics of the features of interest. For example, in order to be able to routinely distinguish between similar cover types, it is necessary to have a good understanding of the spectral characteristics of the cover types of interest. The Corps of Engineer's Topographic Engineering Center (TEC), as well as other facilities, are currently conducting "greenhouse" experiments where the spectral signatures of surface cover types are being catalogued in "signature banks." These signature banks will allow researchers to be selective in terms of the channels they select to process out the set of available wavebands. This will reduce the need to process so many channels of data concurrently and limit the size of the image files to be processed. Signature banks could also be used in the future for developing automated techniques for processing hyperspectral imagery. Computers could examine the spectral signatures from all 200 or so spectral channels, compare them to the a huge signature bank, and make accurate decisions as to the composition of the imaged area. This type of analysis is already being conducted in the western United States for geological mapping applications, as the spectral signatures of rocks and minerals are much easier to catalog and are static in nature as opposed to vegetation.

Another limitation of hyperspectral data at this point is the cost of data from hyperspectral platforms. Very few hyperspectral sensors currently exist and data from these sensors are extremely costly. It is also very difficult to schedule overflights from these sensors as they are currently oversubscribed. This limits the usefulness of hyperspectral data at this time; however, with the launch of the HIRIS system, towards the end of this decade, these limitations will no longer apply. It is incumbent on the wetlands research community to encourage further, much more detailed, investigations into the utility of these data for monitoring our wetland resources so that, once data from spaceborne platforms are available, the data may be fully exploited for wetland applications.

FOR MORE INFORMATION CONCERNING THE USE OF HYPERSPECTRAL DATA WITHIN THE CORPS: The Corps of Engineers has establish a Remote Sensing/GIS Support Center to assist in the application of remote sensing technologies. The address is:

U.S. Army Cold Regions Research & Engineering Center
ATTN: Remote Sensing/GIS Support Center (CECRL-RSGISC)/Dr. H. McKim
72 Lyme Road
Hanover, NH 03755-1290
(603)646-4372

Also, the U.S. Army Topographic Engineering Center (TEC), Fort Belvoir, VA, is conducting research on use of Hyperspectral Data and additional information can be obtained by contacting:

U.S. Army Topographic Engineering Center
ATTN: Dr. Jack Rinker
Fort Belvoir, VA 22060-5546

POINTS OF CONTACT FOR ADDITIONAL INFORMATION: Mr. Mark Graves, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-EN-C, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, phone: (601)634-2557.

Framework for Wetland Systems Management: Earth Sciences Perspective

PURPOSE: The capacity of wetlands to provide specific functions is inextricably linked to characteristics and processes of the surrounding landscape, and therefore effective wetland stewardship and management must operate within a landscape context. This technical note provides fundamental concepts for managing wetlands by summarizing a comprehensive and systematic framework for managing wetlands as interactive components of landscape systems (Warne and Smith 1995).

BACKGROUND: Effective wetland stewardship and management requires a thorough understanding of many wetland and landscape components and processes, and their interactions. Data sources and principles and methods for evaluating the climate, geology, and hydrology of landscape and wetland systems are described in Warne and Smith (1995). The framework presented here provides guidance for formulating and implementing a comprehensive wetland management program (Figure 1) in three principal phases: (1) plan formulation, (2) information development, and (3) program implementation. Procedures for carrying out these phases are briefly discussed below.

FORMULATING A MANAGEMENT PLAN (PHASE 1): A wetland management program begins by formulating a realistic and viable, yet flexible, monitoring and management plan that incorporates seven steps: (1) defining underlying management concerns, (2) assessing available resources, (3) establishing goals in the context of available resources, (4) determining the size of the landscape to be evaluated, (5) establishing an initial action plan that is capable of attaining prescribed goals, (6) organizing management teams, and (7) establishing an education program. In practice, development of many of these steps occurs simultaneously because decisions regarding procedures in one step are interrelated to those of other steps. Underlying management concerns involve mandates, criteria, regulations, orders, and environmental concerns that prompted development of the wetland management program. Management goals and practices are to be tailored to address these concerns.

A viable wetland management plan considers available resources of money, data, and personnel. This consideration cannot be overemphasized. If resources are not available, the program will fail. A simple but comprehensive plan is preferable to an elaborate plan that must later be curtailed. Early recognition of those phases of the program that are resource intensive (monitoring, data compilation, etc.), and evaluation of their cost in terms of time and money, serves as a basis for determining the scale and depth of detail of monitoring and analysis in the management program.

Goals incorporate, as appropriate, maintenance and enhancement of particular wetland functions, protection of certain fauna or flora, and objectives of environmental programs being carried out in the area by other federal, state, or local agencies. The overall goal, however, is to manage wetlands and their functions in a landscape context. Effective goals include a timetable that demarcates when specific tasks (collection, compilation and analysis of historical data, compilation of land cover and land use maps, etc.) are to be completed.

Defining the areal extent of the landscape to be monitored and analyzed begins by considering the drainage basin that contributes surface water flow to the wetland. The drainage basin is the fundamental unit for landscape evaluation. If the entire drainage basin is not to be evaluated, the landscape area

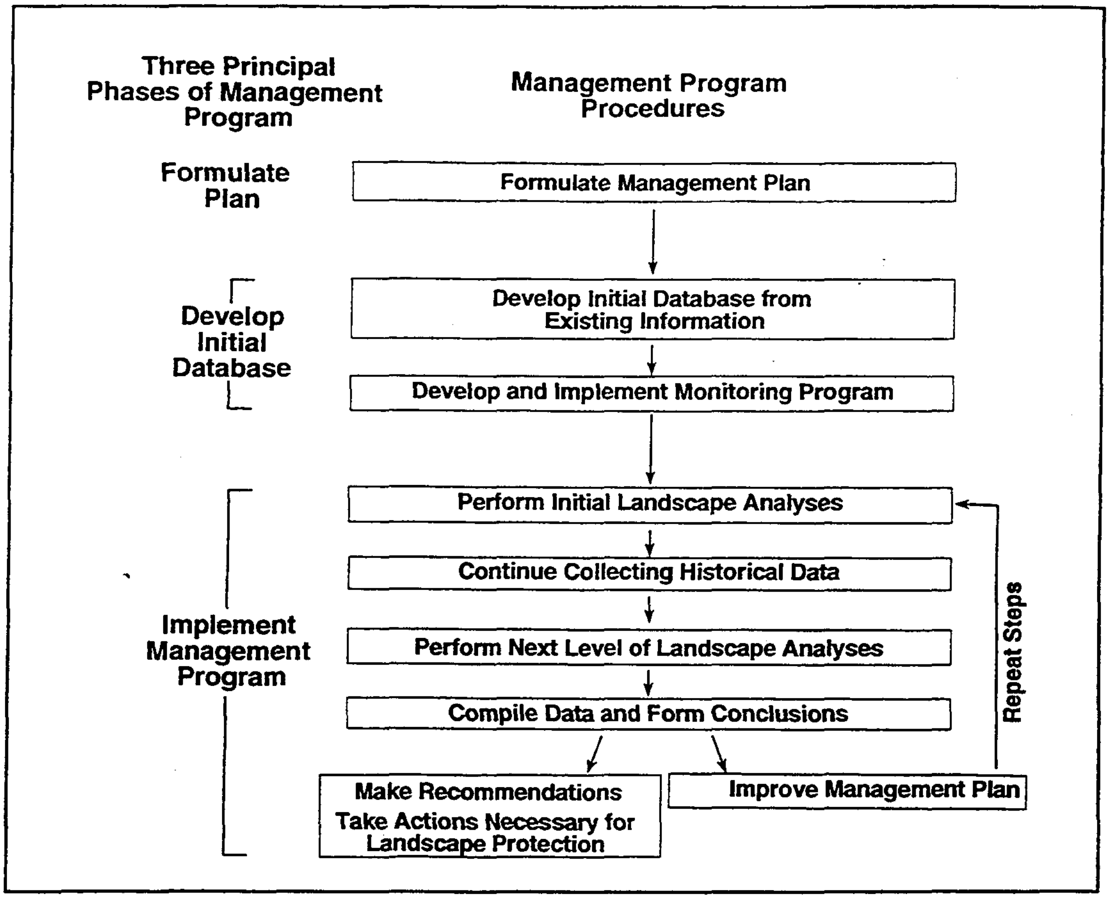

Figure 1. General framework for developing and implementing a wetland management program

should be a subbasin with clearly defined boundaries. Seaba, Kapinos, and Knapp (1987) provide guidelines for defining drainage basins and subbasins. In all cases, principal attributes of the entire drainage basin are considered (land use, land cover, position of the wetland in the watershed, etc.). In addition, regional- and national-scale observations are compiled and analyzed to monitor the effects of large-scale trends on landscape form and process.

An effective working plan is comprehensive, taking into account a broad range of atmospheric, geologic, hydrologic, and biologic aspects of the landscape. Essential elements of the plan include determining scales and resolution of analyses, type of data management and analysis systems to be used, initial data needs, and timetable of initial analysis (Figure 1). A flowchart similar to Figure 1 is a convenient and effective method to outline a working plan.

DEVELOPING AN INITIAL DATABASE (PHASE 2): Detailed assessment of data needs includes identifying relevant existing data and assessing their cost, quality, and applicability (Warne and Smith 1995). Resources should be allocated for ongoing data search, collection, and compilation of existing data. Priorities should be established that define the order in which data are to be acquired and compiled.

A monitoring program should be established after available data have been assessed and inventoried and the essential aspects of the landscape that lack data have been identified (Figure 1). Landscape-scale processes to be monitored may include precipitation, evapotranspiration, temperature, wind speed and direction, sedimentation rates, stream discharge, groundwater movement, plant and animal diversity/abundance, and threatened and endangered species populations. As the management program evolves, the monitoring program may be enhanced. Therefore, monitoring systems such as piezometer nests should be arranged so that additional monitors can be placed in the relevant locations.

IMPLEMENTING THE MANAGEMENT PROGRAM (PHASE 3): After the initial data and the preliminary information from the monitoring program have been compiled, initial landscape analysis is conducted (Figure 1). The initial landscape analysis identifies serious problems that warrant immediate attention, such as water-level fluctuations that inhibit nesting or plant germination, sediment loadings that endanger vegetation or fish populations, and anomalously high nutrient levels. Initial analysis also identifies landscape-scale hydrologic and geomorphic processes critical to maintaining and enhancing specific wetland functions and evaluating landscape and wetland equilibrium states.

The landscape is reevaluated as additional data are compiled and analyzed or as management needs warrant (Figure 1). Information is summarized in the form of graphs and composite maps (see Warne and Smith 1995). Primary goals of the monitoring and analysis program are to promote understanding of the landscape's hydrologic and geomorphic systems (Figure 2), and the position and role of the wetland within these systems. Knowing these systems, one can identify critical hydrologic and geomorphic processes affecting wetland functions, landscape equilibrium, frequency and type of agents that cause significant changes in the wetland and landscape, and the impact of humans on the wetland.

With an understanding of process-response relationships within a landscape, an effective management strategy can be developed to consider the wetland as an integral part of the landscape. The management strategy should include periodic reevaluation of the current monitoring program. As management concerns change and understanding of the wetland landscape is enhanced, the goals of the program should be reassessed and modified (Figure 1).

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Seabar, P. R., Kapinos, F. P., and Knapp, G. L. (1987). "Hydrologic Unit maps," Water-Supply Paper 2294, U.S. Geological Survey, Reston, VA.

Warne, A. G., and Smith, L. M. (1995). "Framework for wetland systems management: Earth resources perspective," Technical Report WRP-SM-12, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

POINTS OF CONTACT FOR ADDITIONAL INFORMATION: Dr. Andrew G.Warne, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-GG-YH, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, phone: (601) 634-2186, author.

Dr. Lawson M. Smith, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-GG-Y, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, phone: (601) 634-2497, co-author.

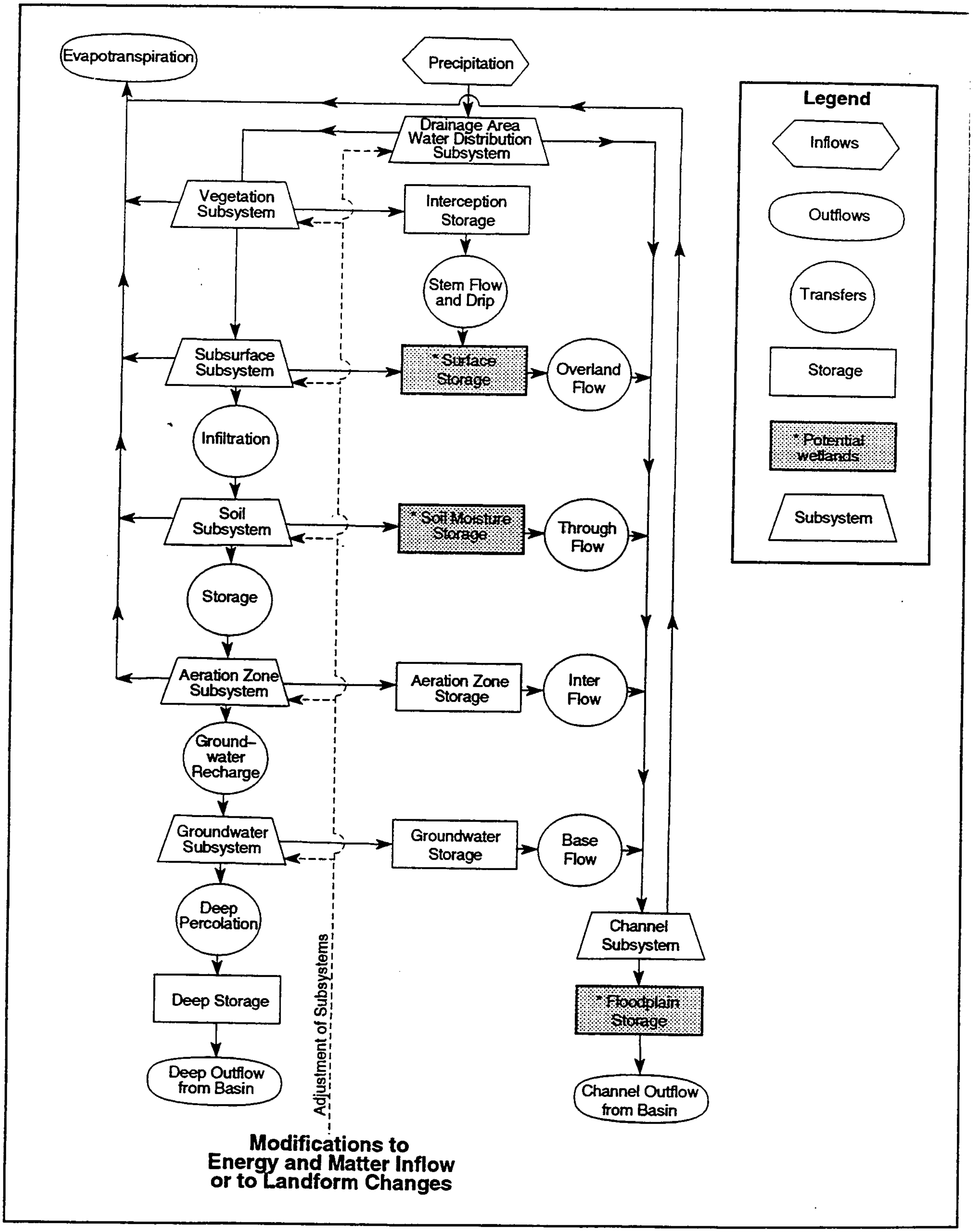

Figure 2. Schematic diagram showing basic exchanges and storages involved in a basin hydrologic cycle (after Chorley, Schumm, and Sugden 1985)

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Bioengineering Technique Used for Reservoir Shoreline Erosion Control in Germany

PURPOSE: This technical note documents a low-cost bioengineering technique for reservoir and lake shoreline erosion control used in Germany, and describes how the technique can be applied in the United States.

BACKGROUND: The bioengineering technique used in Germany for erosion control includes a relatively low-cost biodegradable breakwater with wetlands located shoreward. The technique has application for shoreline erosion control on many U.S. reservoirs with dense thickets of young, woody trees, e.g. willow, cottonwood, and alder, located near them since these materials are used in the breakwater. In Germany, the technique has only been applied where water levels do not fluctuate more than 1 m, however, the technique may be acceptable in situations with greater fluctuations.

The technique was adapted from a method used to regain land lost to the North Sea along the North German coastline. The technique was adapted for use in a demonstration study on the Havel Lake in Berlin 8 years ago. Historically, a wetland fringe along most of the lake's perimeter served to reduce wave energies and protect the shoreline from erosion. In recent times, the lake began to lose shoreline due to the impacts of urbanization on the wetlands. The wetlands were being gradually destroyed by a combination of one or more of the following (list is not exhaustive):

- Waves from motorboats (work and sport)
- Choking out by drifting garbage
- Trampling from people and boats which kinks stems
- Depredation by waterfowl (overpopulated due to feeding by people)
- Discharge of toxins and contamination of water by oil, heavy metals, etc.
- Shading of woods close to the shore

Several kilometers of wetlands have been and continue to be restored along the shore, and the shore is now being protected using this technique or a modification of the technique.

The lake forms part of the Havel River, and its water level is controlled within 0.8 to 1.0 m in the vicinity of Berlin. The wind fetches vary from 2 to 5 km.

BIOENGINEERING TECHNIQUE USED: The technique is a combination of a breakwater and planted wetlands shoreward of the breakwater (Figure 1). Wetland plants are often pregrown in a coconut fiber substrate in one of the following forms: fiber pallets (80 by 125 cm); coconut fiber vegetation carpets that are rolled out onsite (0.5 to 2.0 m wide by 5 m long); and 20- by 20- by 20-cm bulbs. All of these forms lend themselves to immediate transfer to the site and short-term shore stabilization until the vegetation becomes established. Wetlands are not usually planted until the breakwater is in place.

The breakwater can be constructed from various materials, e.g., stone or rocks, branches and poles, or fiberschines (large coconut fiber rolls) (Figure 2). This note focuses on one of the more commonly used

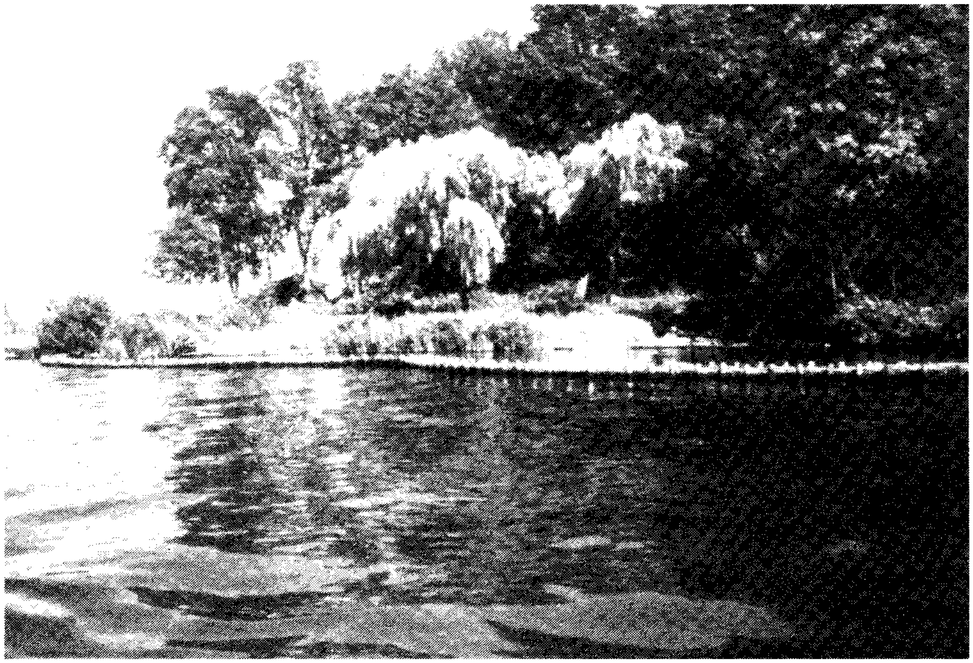

Figure 1. Combination low-cost breakwater with planted wetlands for shoreline erosion control and habitat development

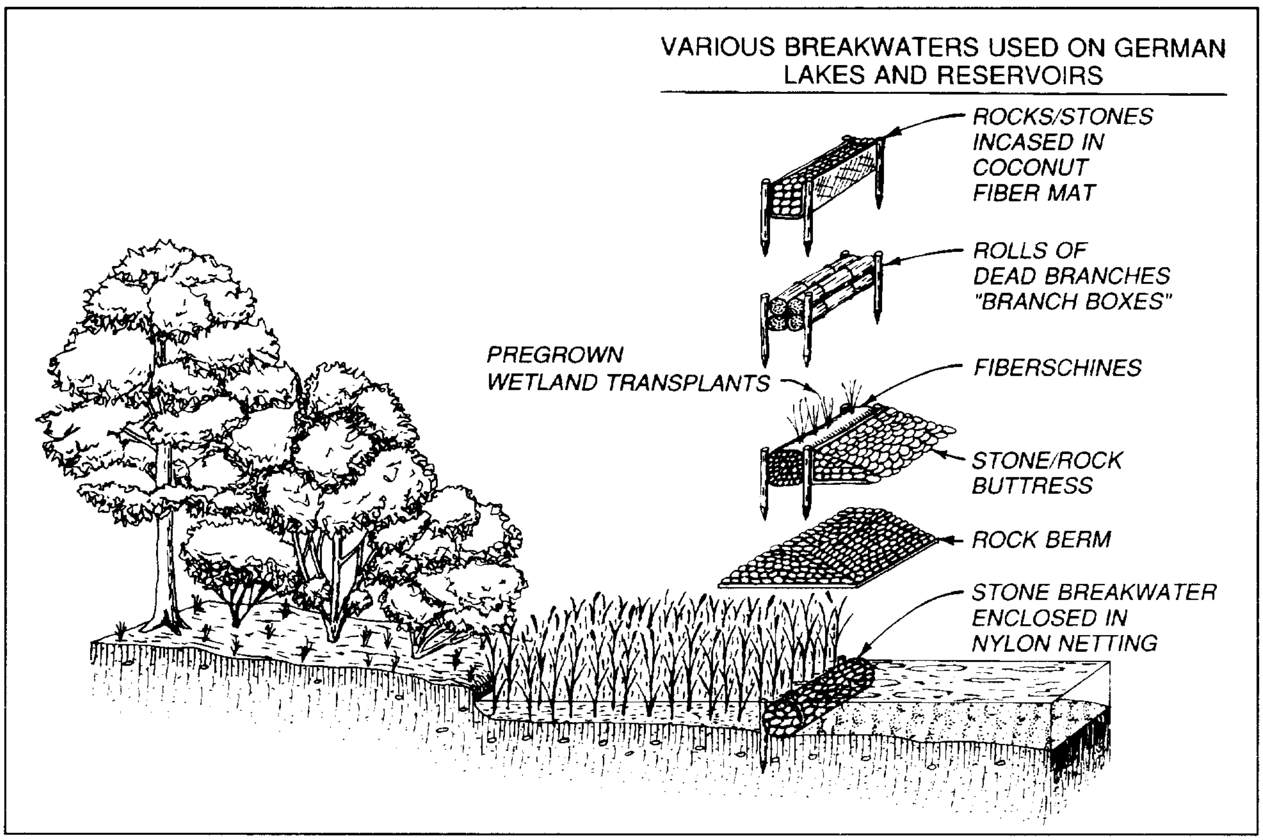

Figure 2. Various combinations of breakwaters and wetlands used on German reservoir and lake shorelines

breakwaters, the branchbox breakwater, which consists of biodegradable materials composed of long poles and faschines (bundles of small dead branches, such as willow and poplar, collected from woodlands (Figure 3)). The breakwater is usually constructed in about 1-m-deep water in the following sequence:

- Place 2- to 3-m-long poles vertically in the lake substrate in two rows about 1 m apart. This is accomplished initially by a hydraulic jet pump; at this point, the poles are not inserted all the way into the substrate, but deep enough to be secure (Figure 4).
- Place a 25-cm-thick layer of dead branches perpendicular to the rows of poles. The branches should be about 1.5 m long. These branches serve as filter material and retard scour at the bottom of the breakwater.
- Wedge faschines between the rows of poles and secure the bundles to the poles by weaving wire rope through screw eyes on each pole like a shoelace; each faschine is about 0.5 m in diameter and varies from 2 to 4 m in length; the screw eyes are placed on the poles a few centimeters above the faschines.
- Drive the poles down firmly with a pneumatic hammer mounted on a barge or some other mechanical device. This tightens the entire breakwater system.
- Cut off the tops of the poles to about 30 to 60 cm above the tops of the faschines, thereby completing the breakwater (Figure 5).

After breakwater construction, wetland plants pregrown in fiberschines, pallets, and bulbs are transferred intact to the site and installed. The fiberschines and pallets are secured to the substrate by driving long stakes into them and tying a rope between the stakes. The construction is then tightened by further driving the stakes into the substrate so that all is secure.

Wetland plants most often used in the lake around Berlin included the following:

- *Acorus calamus* — Sweetflag
- *Carex gracilis* — Sedge

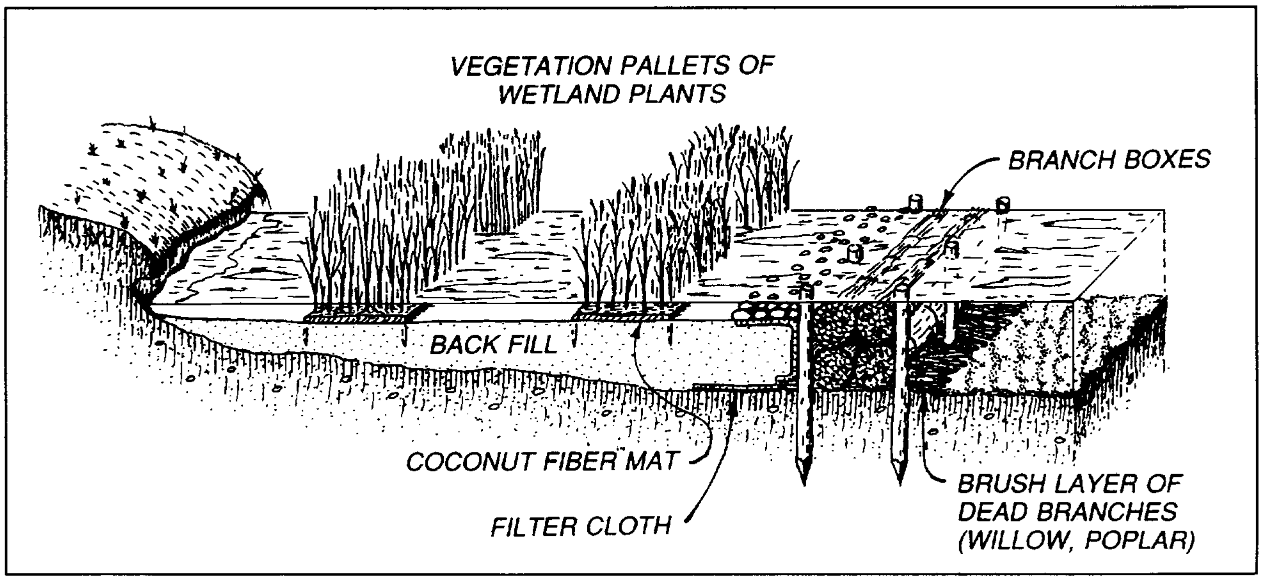

Figure 3. Branchbox breakwater with wetlands shoreward

Figure 4. Poles that are initially placed with a jetpump

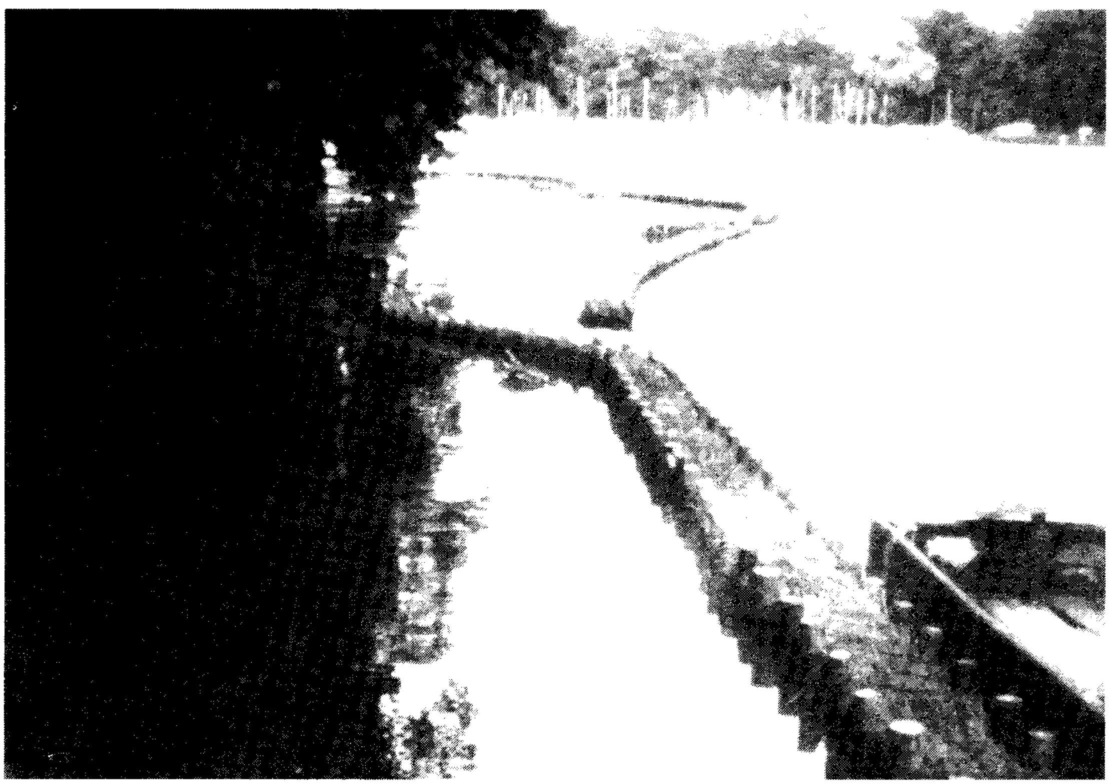

Figure 5. Completed branchbox breakwater

- *Iris pseudacorus* — Yellow flag
- *Phragmites australis* — Common reed
- *Schoenoplectus lacustris* — Bulrush
- *Typha anhustifolia* — Narrowleaved cattail
- *Typha latifolia* — Broadleaved cattail

These wetland plants and others are usually placed in zones of water levels varying between approximately 0.5 m below average water level and about 0.3 m above the average water level.

COSTS: For this wetland system (1991 prices) including the branchbox breakwater, wetland plants installed as pallets and bulbs, and coconut-fiber filter fabric were between $400 and $460 per linear meter for a 10- to 20-m swath from the breakwater landward. Generally, costs for bioengineering alternatives are a fraction of the costs of traditional alternatives such as riprap armorment. It should be noted that construction costs could be lower in Germany because of the existing equipment such as barge-mounted pneumatic hammers and shallow-draft barges and boats. Similar equipment could be made in the United States, however.

CONCLUSION: The branchbox breakwater with associated wetlands is a feasible technique for cost effectively controlling shoreline erosion in reservoirs with little water-level fluctuation. It has the added benefit of providing wetland habitat in harmony with nature. The breakwater is also biodegradable, which improves its acceptability to environmental agencies and groups. This system can be used on reservoir shorelines receiving fluctuation in excess of 1 m, but caution should be exercised and a low-cost demonstration is advised before pursuing large-scale shoreline erosion control efforts on reservoirs of this type.

ADVANTAGES: This technique permits effective, low-cost erosion control without destroying shoreline habitat; in fact, wetlands which enhance the reservoir's shoreline habitat are created. In addition, the wetlands provide sediment entrapment, water quality improvement, aesthetic quality improvement, protection of cultural and archeological resources, and other beneficial functions.

AVAILABILITY: Various modifications of the technique have been used on reservoirs and lakes near Berlin, Pritzwalk, and many other locations throughout Germany. The technique described below was developed and tested by: Lothar Bestmann, Bestmann Ingenieurbiologie (Bioengineering) GmbH, Pinneberger Str. 203, D-2000 Wedel/Holst., Germany, Phone: 011-49-4103-84036, Fax: 011-49-4103-4104

Information is also available on this technique from the following source: Bestmann Green Systems, Attn: Ms. Wendi Goldsmith, P.O. Box 88, Boston, MA 02133, Phone: (617) 723-9404, Fax: (617) 723-9430

POINT OF CONTACT FOR ADDITIONAL INFORMATION: Mr. Hollis H. Allen, USAE Waterways Experiment Station, ATTN: CEWES-ER-W, 3909 Halls Ferry Road, Vicksburg, MS 39180-3199, Phone: (601) 634-3845.

Wetland Environmental Database: Meeting the Challenge of Federal Geographic Data Acquisition and Access Requirements

PURPOSE: This technical note describes the organization and content of a digital wetland environmental database developed for a portion of the Cache River drainage basin in eastern Arkansas. The database is one of the first DoD environmental databases to conform to several new Federal regulations addressing geographic data acquisition and access which are discussed in this technical note.

BACKGROUND: Technological advances in automated measuring, monitoring, and testing equipment have led to a tremendous increase in the volume of environmental data collected by researchers worldwide. This is especially the case for sensitive environmental resources such as wetlands. In many cases the ability to collect environmental data has exceeded the ability to integrate and analyze the data. Locating, evaluating, and accessing existing data are still widespread problems. Data that are poorly organized, undocumented, or difficult to access are of little use in solving environmental problems. Scientists, engineers, and managers need quick access to well-structured, integrated environmental information to support analysis, modeling, and decision-making.

Recent advances in the ability to electronically locate and access existing environmental data will improve our wetland stewardship capabilities by fostering the exchange of information, avoiding duplication, and stimulating creative problem-solving. In addition, several new Federal regulations include the use of these electronic access technologies as part of their implementation guidance.

WETLAND ENVIRONMENTAL DATABASE: As part of the Corps of Engineers' Wetland Research Program (WRP), the Waterways Experiment Station (WES) investigated methods for compiling, organizing, and accessing digital wetland databases. These investigations addressed technical issues of database design, storage formats, documentation, archive requirements, and electronic data transfer. A prototype database was developed for a portion of the Cache River watershed in eastern Arkansas (Figure 1). The database is archived on compact disk-read only memory (CD-ROM) and distributed as part of a WRP technical report (Kress and Bourne 1995).

Scientific investigations of the Cache River bottomland hardwood forest and the associated watershed have generated a wide variety of environmental data. Included among the types of data that have been acquired to characterize and understand the wetland system are field measurements of physical features, laboratory test results of water samples, numerical modeling output for basin hydrologic conditions, mapped data such as soil type and forest cover, remotely sensed images from satellites, land survey data containing the locations of sample sites, and narrative accounts of previous investigations.

The data included on the CD-ROM (Kress and Bourne 1995) are listed in Table 1. Derived from a variety of sources, each file has an associated text file describing its content, origin, and format. These data are archived in vector, raster, or tabular format as appropriate.

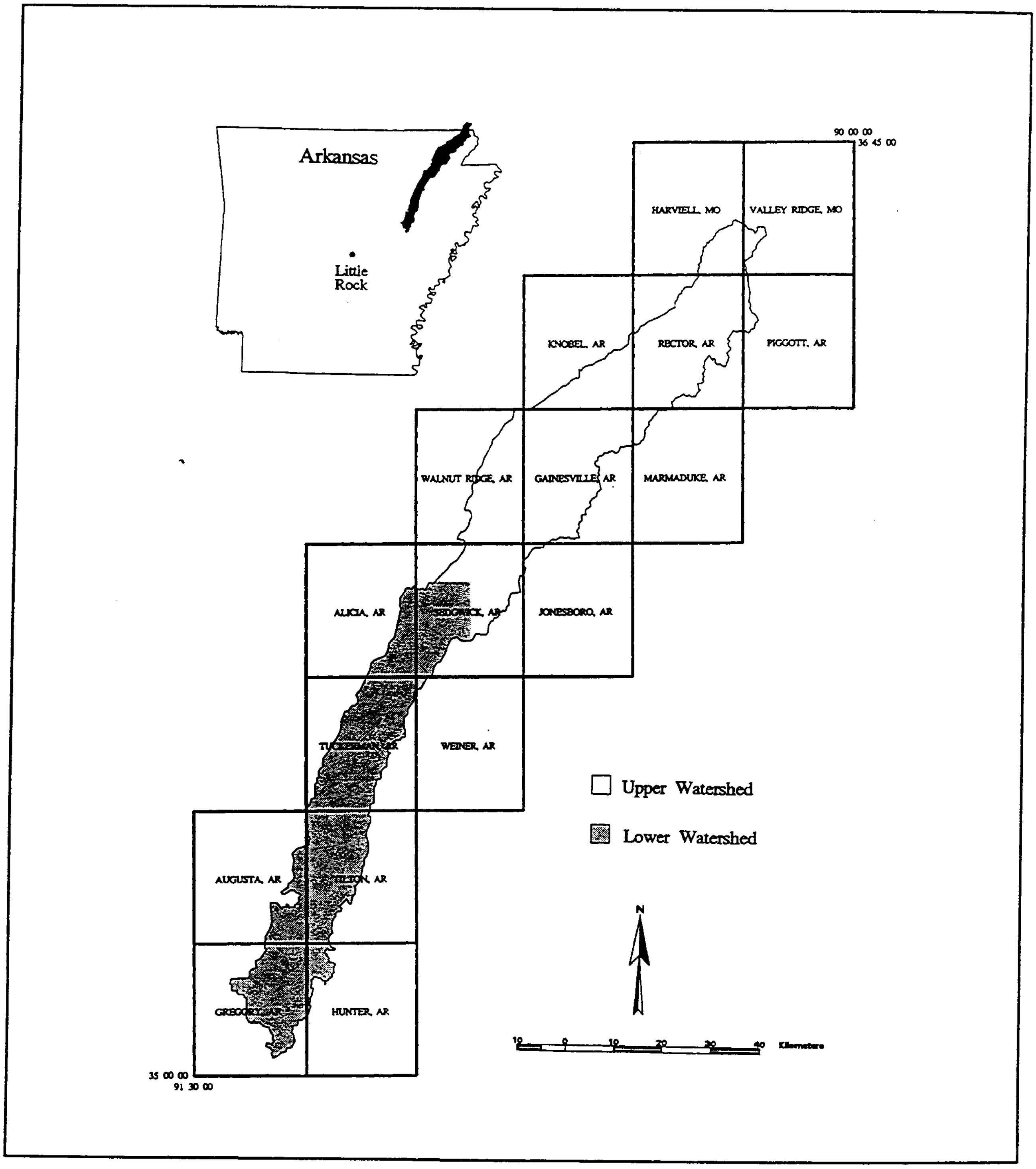

Figure 1. Location and geographic extent of the WRP Cache River Wetland Environmental Database. Grids represent 15- by 15-min blocks used to subset large files for the data archive

Vector data include digital maps of elevation contours, surface hydrology, wetland types, forest cover, and soil types. The vector data are available in three exchange formats. Satellite images and a digital elevation model are stored as raster data in a band interleaved by line format. The Landsat multispectral

Table 1. Content of the WRP Cache River Wetland Environmental Database

Data Type	Source
State boundaries	USGS 1:2M Digital Line Graphs
County boundaries	USGS 1:2M Digital Line Graphs
Surface hydrology	USGS 7.5' topographic maps
Topographic elevation contours	USGS 7.5' topographic maps
Digital elevation model	Interpolated from elevation contours
Forested areas - 1935	USGS 15' topographic maps dated 1930-1940
Forested areas - 1975	USGS 7.5' topographic maps dated 1960-1970
USDA soil series	USDA/SCS county soil surveys
Wetland type - 1990	USFWS/National Wetland Inventory
Satellite images - 1972, 1974, 1976, 1980	Landsat MSS, 4 channel
Forested areas - 1972, 1974, 1976, 1980, 1987	Interpreted from satellite images
Map Index - 1:24,000, 1:62,500	USGS 7.5' and 15' topographic maps
Bird counts by species	Field measurements
Reptile counts by species	Field measurements
Mammal counts by species	Field measurements
Logs - count and length	Field measurements
Snags - counts and length	Field measurements
Saplings - count by species	Field measurements
Seedings - count by species	Field measurements
Subcanopy - count by species	Field measurements
Ground cover - percent cover by species	Field measurements
Tree diameter breast height by species	Field measurements
Tree density by species	Field measurements
Weather data - daily amount	Field measurements
Stream gauge readings - daily	Field measurements
Water quality test results - weekly	Field measurements

scanner images provided on the CD-ROM are not copyrighted. Tabular data include field measurements and observations, results of laboratory tests, and numerical model output. They were collected or generated by various scientists using established and experimental methods. A simple, portable storage format is used for tabular data. The format is a row major, comma delimited ASCII format. Data in this format can be imported by most commercially available statistical, spreadsheet, database, and graphic softwares.

The Cache River database is organized on the CD-ROM in a series of directories and subdirectories. The structure is based primarily on data theme (subject). All data related to a basic theme (such as hydrology or vegetation) are stored together. For large files, a further subdivision based on geographic extent was used to store the data in smaller, manageable files. These geographic subdivisions correspond to the boundaries of the USGS 1:62,500 topographic maps as shown in Figure 1.

EXECUTIVE ORDER 12906: Recognizing that "geographic information is critical to promote economic development, improve our stewardship of natural resources, and protect the environment..." on April 11, 1994, President Clinton signed Executive Order (EO) 12906, "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure." Of central importance in the EO is the documentation and sharing of geospatial data. Geospatial data are defined in the EO as "information that identifies the geographic location and characteristics of natural or constructed features and boundaries on the earth...derived from, among other things, remote sensing, mapping, and surveying technologies." The definition brings to mind various types of map information, but statistical data may be included as well. All data in the WRP Cache River database can be considered geospatial data. The digital database conforms to all current Federal regulations and standards related to geospatial da acquisition, documentation, and access. Three of these new Federal requirements--metadata documer tation, electronic clearinghouse access, and spatial data transfer standard--are discussed below.

METADATA: The EO requires that all geospatial data produced with Federal funds be documented in standardized manner. This standardized documentation is referred to as metadata. The prefix "meta- means beyond or transcending. In the current context, "metadata" are supporting information used t document important characteristics of a file and the data contained in the file. Metadata document th content, quality, condition, and source of the geospatial data. They document who, how, when, an sometimes why the data were collected or produced.

In the WRP Cache River database, every geospatial data file has an associated metadata file. Th metadata are stored as ASCII text and follow guidance found in "Content Standards for Digita Geospatial Metadata," issued by the Federal Geographic Data Committee (FGDC) on June 8, 1994.

Figure 2 illustrates part of a metadata text file. These metadata document digital geospatial data depictin the extent of forested area as shown on the 1:62,500-scale Tuckerman, AR, topographic map dated 1935 The keyword entries are important. Just as a user may search library holdings for books on a certai subject, digital data holdings may be searched by theme keyword (subject) or place keyword (geographi location) through the geospatial data clearinghouse.

CLEARINGHOUSE: The EO also requires that the availability of geospatial data be made know through the National Geospatial Data Clearinghouse. The Clearinghouse is an electronically connecte network of geospatial data producers, managers, and users, established in 1994 by the Federal Geographic Data Committee. The goal of the clearinghouse is to improve access to Federal geospatial data by Federal users and the general public. Agencies must check the Clearinghouse for existing data prior to expending Federal funds to produce geospatial data. Beginning with the FY97 budget cycle, Commanders must certify in writing that the Clearinghouse has been checked for possible duplicate data acquisition efforts.

WES has prepared approximately 100 metadata files for the Clearinghouse informing the public of the availability of the WRP Cache River database. These metadata will allow potential users to determine if the data are applicable for their work and inform them how copies of the database may be obtained. Information about the Clearinghouse is available electronically via Internet mail (*gdc@usgs.gov*) or via the FGDC server, Universal Resource Locator (URL *ftp://fgdc.er.usgs.gov/*). Metadata can be accessed via the World Wide Web at the U.S. Army Corps of Engineers' Geospatial Data Infrastructure (URL *http://corps_geo1.usace.army.mil*).

SPATIAL DATA TRANSFER STANDARD (SDTS): Federal Information Processing Standard 173 specifies the Spatial Data Transfer Standard (SDTS) as the format for official data exchange between Federal agencies (Department of Commerce 1992). The SDTS is a large but flexible set of rules for encoding geospatial data for transfer between dissimilar computer systems. In response to this Federal regulation, commercial vendors are providing import/export capabilities for SDTS.

WES used the topological vector profile of the SDTS to export all vector data for archiving on the CD-ROM. The SDTS translators are just beginning to appear in the commercial market. For this reason, the Cache River data are archived in two additional formats. These are ArcInfo uncompressed export format and ArcInfo ungenerate format. The uncompressed export format can be used by UNIX and DOS versions of ArcInfo and by Intergraph Microstation. The ungenerate format is a simple polygon vector ASCII listing. Complete documentation of the three archive data formats is provided on the CD-ROM (Kress and Bourne 1995).

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FOREST30.MET
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IDENTIFICATION INFORMATION

Citation Information
 Originator:                              US Army Corps of Engineers
                                          Waterways Experiment Station
                                          Environmental Laboratory
 Publication Date:                        10/1/94
 Title:                                   forest30

Publication Information
  Publication Place:                      Vicksburg, Mississippi
  Publisher:                              US Army Corps of Engineers
                                          Waterways Experiment Station
                                          Environmental Laboratory

Description
  Abstract: These data represent forested areas inside the Cache River
AR      watershed as depicted on the Army Map Service 1:62,500 scale
Tuckerman AR topographic map dated 1935.  The data were manually
digitized from non-stable base materials in ArcInfo.  The data are stored
in topological vector format.  The coordinate system is UTM.  Similar
data for adjoining map sheets are also available.

  Purpose: These data were produced as part of a comprehensive study of
the bottomland hardwood wetlands in the watershed of the Cache River AR.
The study was conducted under the US Army, Corps of Engineers, Wetland
Research Program.  The data are used to characterize the historical
extent of bottomland hardwood forest during the 1930's.

Status
 Progress:                                complete
 Maintenance and Update Frequency:        none planned

Spatial Domain
 Bounding Coordinates
  West Bounding Coordinate:               -91.250
  East Bounding Coordinate:               -91.000
  North Bounding Coordinate:               35.750
  South Bounding Coordinate:               35.500

Keywords
 Theme
  Theme Keyword:                          forest cover
  Theme Keyword:                          vegetation
  Theme Keyword:                          landcover
 Place
  Place Keyword:                          Arkansas
  Place Keyword:                          Cache River
  Place Keyword:                          Tuckerman
```

Figure 2. Part of the metadata documentation for a vector file in the WRP Cache River Wetland Environmental Database

The WRP Cache River Database is available through Interlibrary Loan Service by contacting the U.S. Army Engineer Waterways Experiment Station Library, telephone (601) 634-2355 or FAX (601) 634-2542.

REFERENCES:

Department of Commerce. (1992). "Spatial data transfer standard (SDTS) (Federal Information Processing Standard 173)," National Institute of Standards and Technology, Washington, DC.

Executive Order 12906. (13 Apr 94). "Coordinating geographic data acquisition and access: The national spatial data infrastructure," *Federal Register* 59(71), 17671-74.

Kress, R., and Bourne, S. (1995). "Cache River Basin, Arkansas: Environmental database, compact disk data archive, and metadata documentation," Technical Report WRP-SM-13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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